

NASA Technical Memorandum 104563

**An Atlas of Upper Tropospheric
Radiances Observed in the 6 to 7-
Micrometer Water Vapor Band
Using TOVS Data from the NOAA
Weather Satellites During 1979-1991**

Dennis Chesters and Om Sharma

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ABSTRACT

This document is a pictorial atlas of the Earth's radiance emitted in the 6 to 7 μm water vapor band. At these wavelengths, the infrared brightness temperature corresponds to the layer-average temperature of the top few millimeters of water vapor in the atmosphere. At low latitudes, bright regions are dry slots in the upper troposphere. The satellite observations were obtained from NOAA's cloud- and angle-corrected measurements made by a series of polar-orbiting TOVS (TIROS Operational Vertical Sounder) instruments flown from 1979 to 1991. TOVS 6.7 μm and 7.2 μm channels were converted to a single brightness temperature that simulates a high-altitude channel near "6.5" μm . For climatological studies, the daily "6.5" μm overpass data were gridded to a Cartesian projection with $5^\circ \times 5^\circ$ horizontal resolution between 40N and 40S latitude. This atlas presents greyscale images of the "6.5" μm brightness fields for every day in every month for 13 years. The mean brightness for each of the 12 months for 13 years is presented to display inter-annual variability, and the annual cycle of 12 monthly means is summarized on a single page. Statistical summaries are presented from other investigations in progress.

THE TOVS "6.5" μm DATABASE

Most meteorological satellites employ a 6.7 μm channel to display the upper air water vapor. At mid-latitudes, meteorologists (Weldon and Holmes, 1991) relate the synoptic-scale 6.7 μm features to the strong upper air dynamics and thermal structures associated with baroclinic zones. At low latitudes, satellites measure the brightness temperature of the top few millimeters of water vapor in the atmosphere (Stout et al, 1984). In the barotropic zones at low latitudes, temperature variations are only ± 2 to ± 3 C, while the corresponding dewpoints vary by ± 20 to ± 30 C (Schubert et al, 1990). Consequently, the 6 to 7 μm satellite radiances at low latitudes are dominated by variations in the upper tropospheric moisture content, where bright regions indicate dry slots and dark regions indicate moist mounds in the upper air.

Radiance Transformations to "6.5" μm

Since 1979, NOAA has been flying a self-consistent series of operational weather satellites carrying the TOVS system (TIROS Operational Vertical Sounder), a calibrated set of infrared and microwave radiometers. TOVS includes infrared channels at 6.7 and 7.2 μm , located on the bright longwave shoulder of the strong water vapor absorption band centered at 6.5 μm . During the previous decade, NOAA operations preprocessed the TOVS infrared and microwave channels to correct for cloud amount, spot size and viewing angle. The cloud- and angle-corrected brightness temperatures are normally used to make operational temperature soundings over the globe. NOAA archives the preprocessed data on 9-track magnetic tapes.

To estimate the brightness temperature at the center of the "6.5" μm band, the following combination of TOVS cloud-corrected 6.7 μm and 7.2 μm brightnesses was used:

$$T^*(\text{"6.5" } \mu\text{m}) = 1.5 T^*(6.7 \mu\text{m}) - 0.5 T^*(7.2 \mu\text{m}).$$

This combination has an effective weighting function that peaks at approximately 350 mb, with some small negation of lower-level variations (see Fig. 1). The "6.5" μm brightness temperature is the average temperature of the top few millimeters of precipitable water in the atmosphere.

hemisphere) normally results in strong large-scale features in the upper air water vapor, while summer meteorology (in the northern hemisphere) results in weaker, less well-defined patterns. Because NOAA's meteorological analysis uses the surrounding observations where there were missing orbits or high clouds, radiance observations of high cloud tops are truncated from the database and replaced with the mean from nearby partly cloudy regions. Zonal symmetry is enhanced by the longitudinal averaging scheme employed by NOAA's objective analysis.

Fig. 2 contains several climatological features that are typical for this time of year. Contour lines are drawn at 228, 236, 244 and 252 K, the normal range of "6.5" μm brightness temperatures. The deepest (hottest) dry slot in the summertime northern hemisphere is located over the Middle East, in the middle of the lower right quadrant of Fig 2a. The deepest (hottest) dry slots in the wintertime southern hemisphere are located at 120W over the central Pacific and at 90E over the south Indian Ocean, located at the bottom and right sides, respectively, of Fig. 2b. Of course, the lowest brightness (<228 K) occurs over the Antarctic in the center of Fig. 2b.

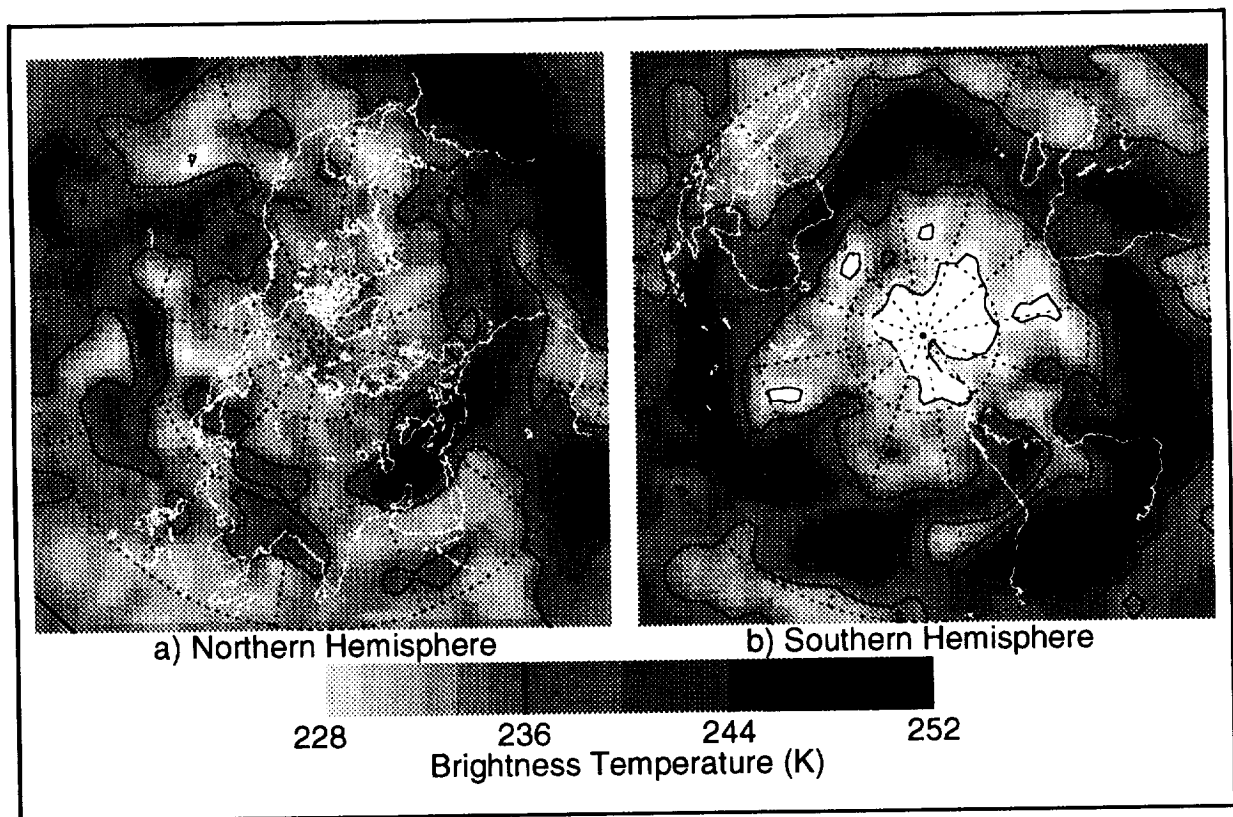


Fig. 2 An example of NOAA's polar stereographic analyses of TOVS "6.5" μm brightness temperatures for the a) northern and b) southern hemispheres. Each image represents a grid of 65x65 cells of objectively analyzed data for 4 July 1983. Longitudes and latitudes are marked at 30° intervals as black dashed lines, and continental outlines are overlaid as white solid lines.

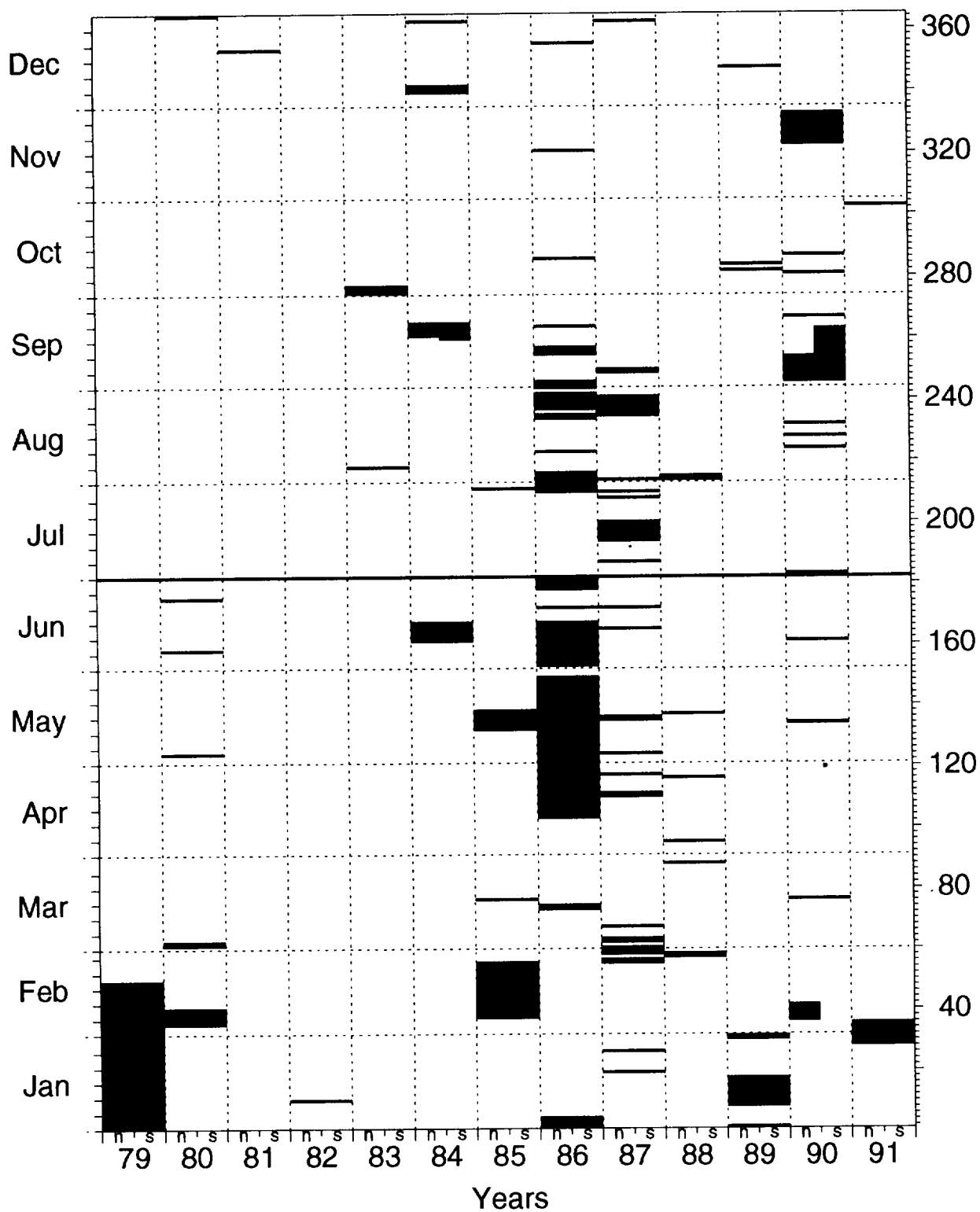


Fig. 4 A graphical presentation of the list of days without useful observations in the "6.5" μm TOVS database from 1979 to 1991. Horizontal black bars indicate missing or unavailable data in one or both (north or south) hemispheres for a day or group of days.

TOVS UPPER AIR WATER VAPOR IMAGES (SEE APPENDICES)

Daily Resolution (Appendix A)

Images for every day in the thirteen years of TOVS "6.5" μm data are presented in Appendix A. They provide a lively view of synoptic-scale upper air moisture on a global scale.

Each page in Appendix A displays daily images for an entire month. Empty (white) boxes indicate missing or unacceptable data for that day. The first day in each row of three days is numbered along the left hand margin, for up to eleven rows. Each day's image is a Cartesian projection – the horizontal axis goes from 0E to 360E longitude in 5° steps for a total of 72 grid cells, and the vertical axis goes from 40S to 40N latitude in 5° steps for a total of 17 grid cells. Outlines of the continents (in thin white lines) are overlaid on the image. The maximum and minimum brightness temperature displayed are 252 K and 228 K, respectively. Contour lines at 8 K increments help to delineate the significant low-middle-high brightness features of the data. Occasional off-scale values are reset to the nearest gray level of the minimum or maximum brightness temperature.

The daily images in Appendix A provide the opportunity to study the extent and duration of events within a region of climatological interest. For example, consider January 1984 (on page A-62). The main climatological feature here is a region of high brightness temperature over the central north Pacific ocean. This region actually displays three growth and decay cycles with a period of 13 to 17 days during the months of January through March 1984. Comparisons with other data sets are being made to understand the significance of such events. In addition, features can be observed at the high resolution limits of this climatological space-time grid that appear related to synoptic and mesoscale meteorology.

Monthly Resolution (Appendix B)

Appendix B presents monthly averages of the TOVS "6.5" μm brightness temperatures, using the data presented at daily resolution in Appendix A. Months which had substantial (greater than 70%) missing or unavailable data are indicated by empty boxes. The format of individual images in Appendix B is similar to Appendix A. The layout on each page of Appendix B is designed to allow the user to see the inter-annual variability; the observations for the same month in succeeding years is presenting in a column, so that the eye can scan up-and-down.

Unfortunately, only a column of 9 years can be printed on one page without making the images too small to be useful. Therefore, the 13 years of monthly average data are printed in two

SOME STATISTICS OF THE ANNUAL AND INTER-ANNUAL CYCLES

In a previous climatological study (Chesters and Neuendorffer, 1991), the TOVS "6.5" μm water vapor brightnesses from 1979-1989 were compared to the corresponding Outgoing Longwave Radiation (OLR) heat flux from the 11 μm AVHRR channel on the NOAA satellites. OLR 11 μm fluxes are an indicator of vigorous convection at low latitudes on time scales from weeks to decades (Lau and Chan, 1986).

Figure 6 presents one such comparison between the annual cycles of the average OLR 11 μm and TOVS "6.5" μm brightness averaged over the entire Eastern and Western tropical Hemispheres (0E to 180E and 0W to 180W, both 30N to 30S). The cloud-dominated OLR has a strong semi-annual cycle with out-of-phase hemispheric components, but the cloud-corrected TOVS brightness shows an unexpectedly weak semi-annual cycle with the same phase in both hemispheres. The low-latitude "6.5" μm brightness temperature averaged over the tropics is a steady 238 ± 0.5 K.

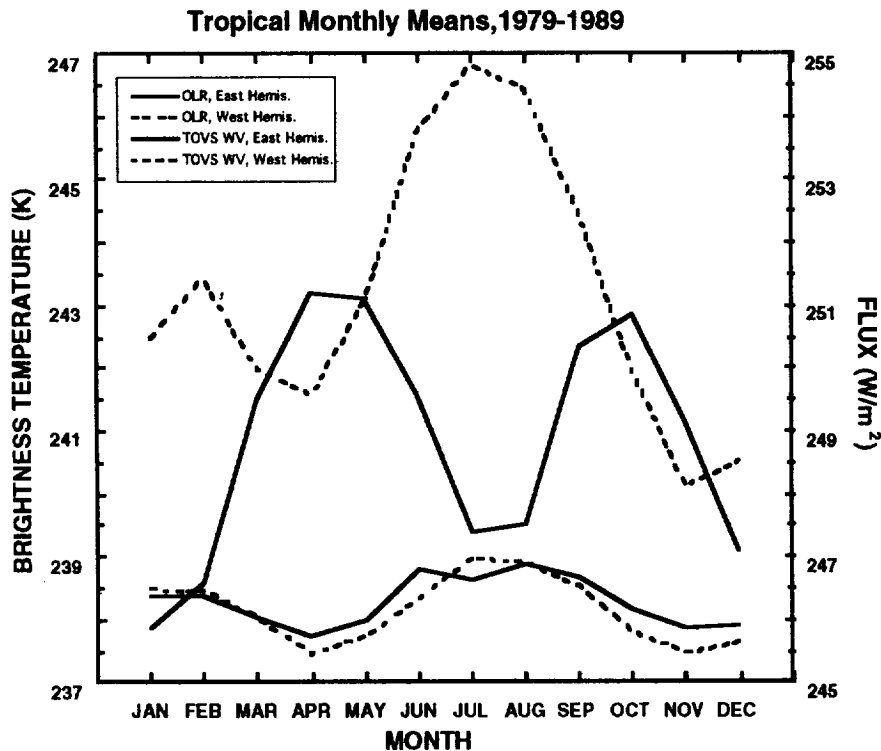


Fig. 6 The annual cycle of TOVS "6.5" μm brightness temperature (bottom two curves) compared to OLR 11 μm upwelling flux (top two curves) for the Eastern (solid lines) and Western (dashed lines) tropical Hemispheres (30N to 30S) at monthly resolution averaged over 1979-1989.

Figure 8 presents two 11-year time-series of TOVS "6.5" μm brightness from the preliminary climatological time-series for 1979-1989. At 40N, the brightness appears to be dominated by the late summer subsidence over the Middle East. At 10N, the annual oscillations are 6 months out of phase with the 40N pattern, and are apparently dominated by the cross-equatorial subsidence of the air from the Southern Hemisphere during austral summer. Each latitude band has its own characteristics (not shown for lack of space). **The effects of ENSO in 1982-83 (months 48 to 60) and in 1987-88 (months 96 to 108) are unexpectedly absent in all the zonal means.** There also is other peculiar behavior during 1987-1989 which may be due to poor calibration on the NOAA-9 satellite flying at the time, which requires further study.

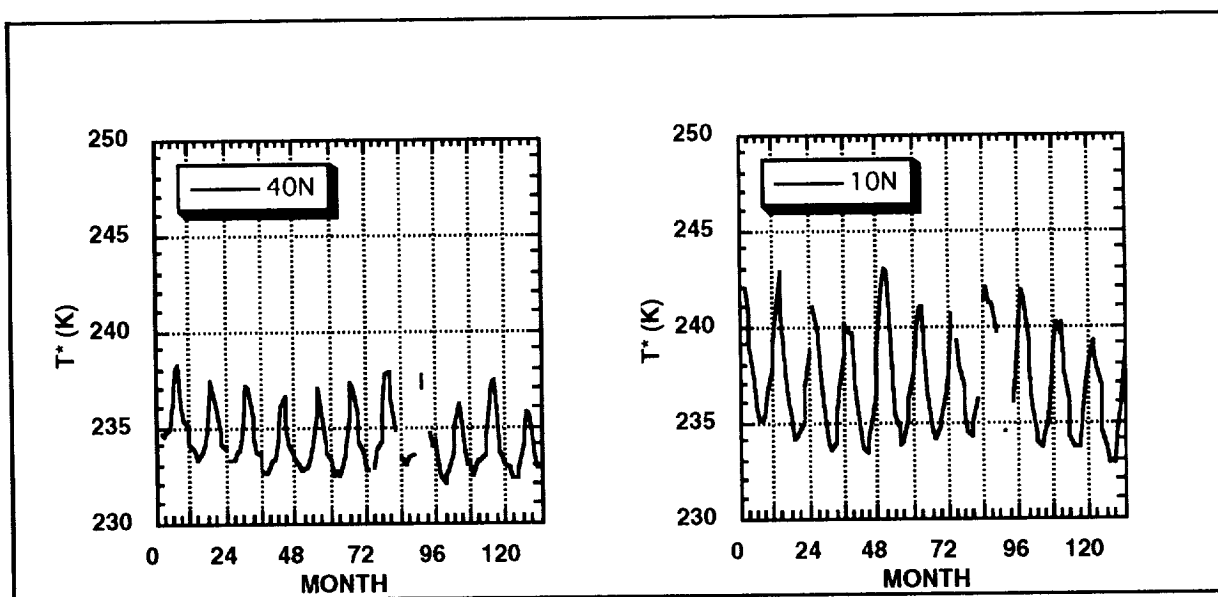


Fig. 8 The 11 year cycle of TOVS "6.5" μm brightness temperature in latitude bands at 40N (left) and 10N (right) during 1979-1989. Breaks in the monthly means are due to problems with replaying the NOAA archives on the first attempt.

the first half of 1983, these patterns were disturbed by an ENSO event, visible as anomalously dark features propagating into the normally bright air above Eastern Pacific. Wu, et al. (1992) have performed an Empirical Orthogonal Function (EOF) analysis of the TOVS 6.7 μm radiances, demonstrating that the first EOF corresponds to the ENSO pattern and accounts for 25% of the variability in the radiances.

In addition to these climatological features, Figure 9 illustrates the existence of unexpectedly strong synoptic features at the equator. These appear in the form of long thin diagonal streaks which represent steadily propagating disturbances sometimes in groups to the east (upward to the right), sometimes to the west (upward to the left), and sometimes in both directions. **Some disturbances in the "6.5" μm radiances are able to circumnavigate the Earth a few times, able to freely cross both each other and the terrain barriers at the equator. Propagation speeds appear remarkably constant, with disturbances typically circumnavigating the Earth in approximately 30 to 60 days.**

DISCUSSION AND CONCLUSIONS

The large scale climatological features are established for the TOVS "6.5" μm database in the NOAA satellite archives. Cold, high, moist air is observed above the annual monsoons and the ENSO cloud-driven outbreaks in the eastern Pacific in 1982-3 and 1987-8, mimicking the corresponding behavior observed in the satellite-derived OLR flux. **However, we find little sensitivity in the global or zonal means to the annual cycle or to ENSO events by the upper air brightness in the 6 to 7 μm band. Unexpectedly robust fine scale features appear to continually circumnavigate the Equator every 30 to 60 days.**

Regional and synoptic "6.5" μm features are significantly variable. Careful comparison with other satellite and conventional fields should establish reliable interpretations in terms of upper air advection, subsidence, and regional oscillations. Hasler et al. (1992) are experimenting with high-performance animations of the TOVS water vapor imagery, inventing ways to probe this unique climatological indicator of upper tropospheric activity. Eventually, the unambiguous signatures of upper tropospheric moisture that appear in the TOVS 6 to 7 μm satellite radiances are expected to become an empirical diagnostic tool for judging the accuracy of upper air dynamic processes and the water budgets forecast by numerical weather and climate models.

APPENDIX A (DAILY IMAGES)

TOVS "6.5" μm IMAGES

EACH DAY IN EVERY MONTH OF EVERY YEAR

1979-1991

TOVS 6.5 μ m Water Vapor Band

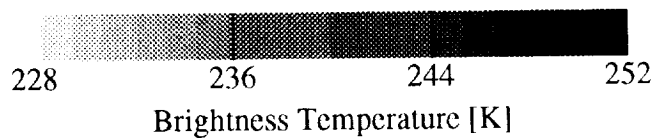
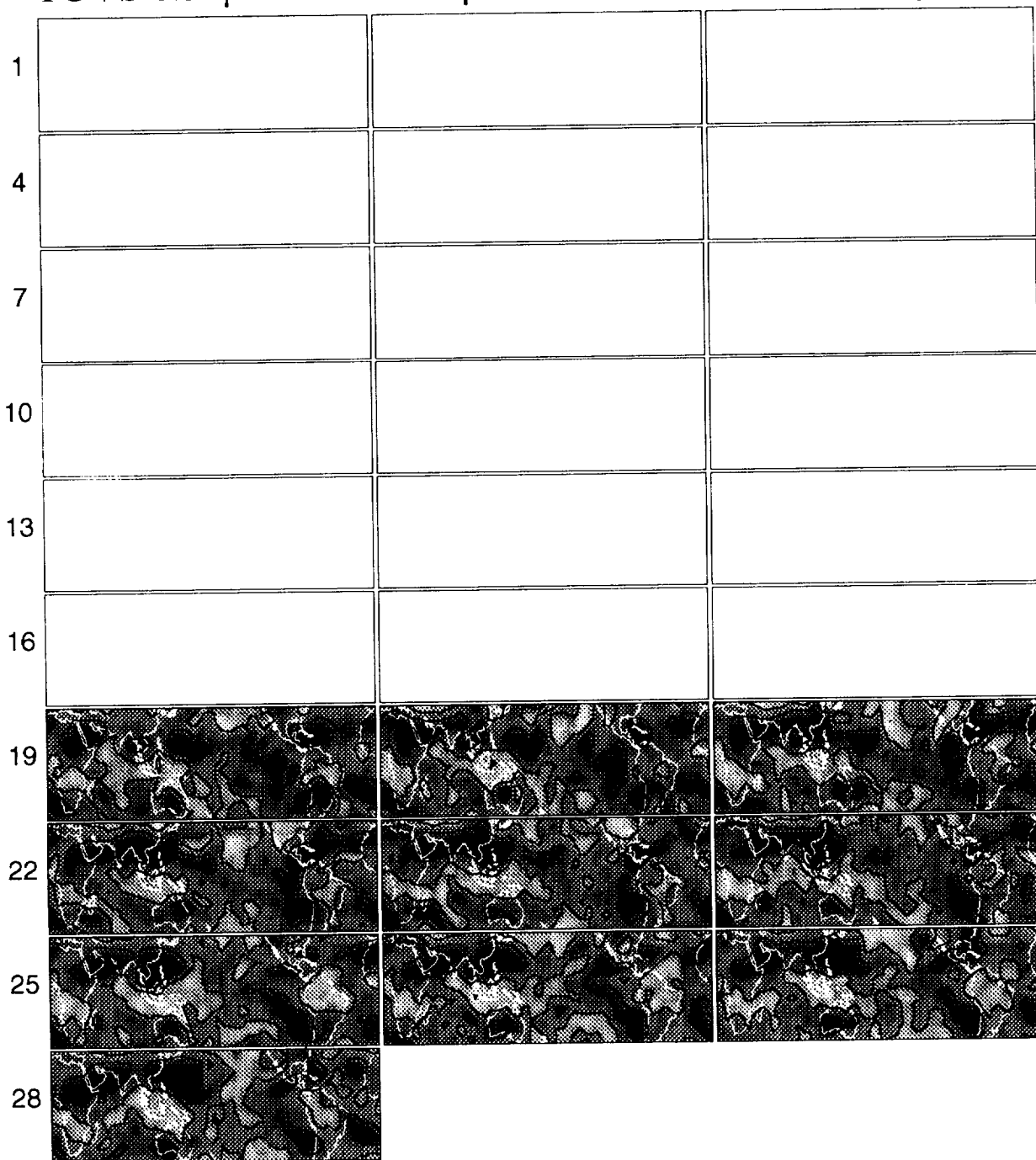
January 1979

1			
4			
7			
10			
13			
16			
19			
22			
25			
28			
31			



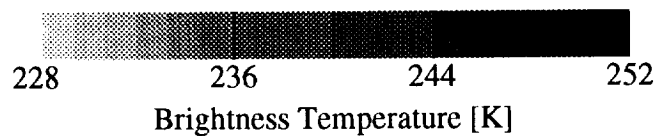
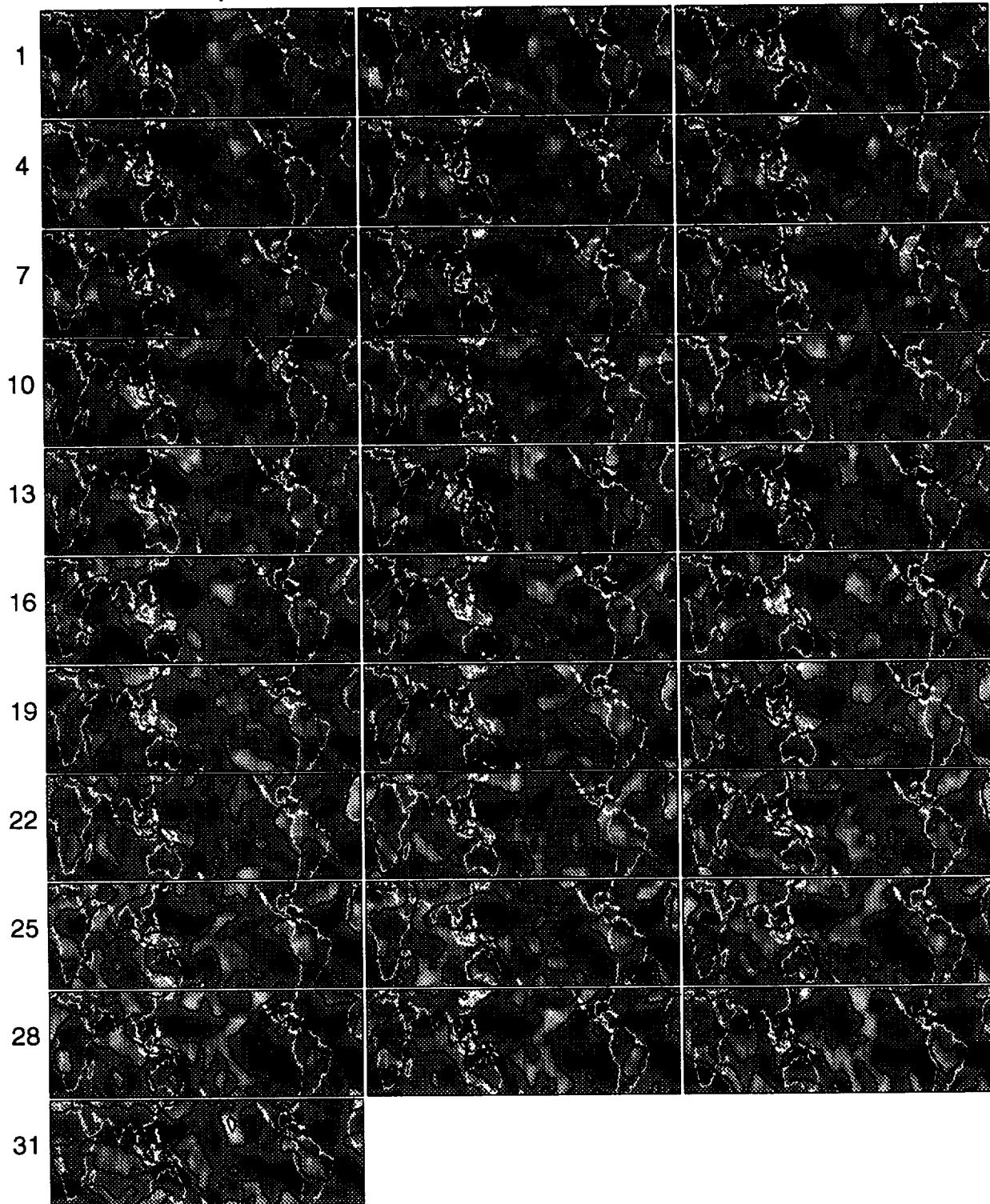
TOVS 6.5 μm Water Vapor Band

February 1979



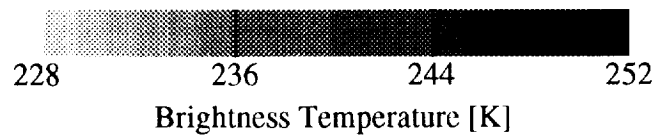
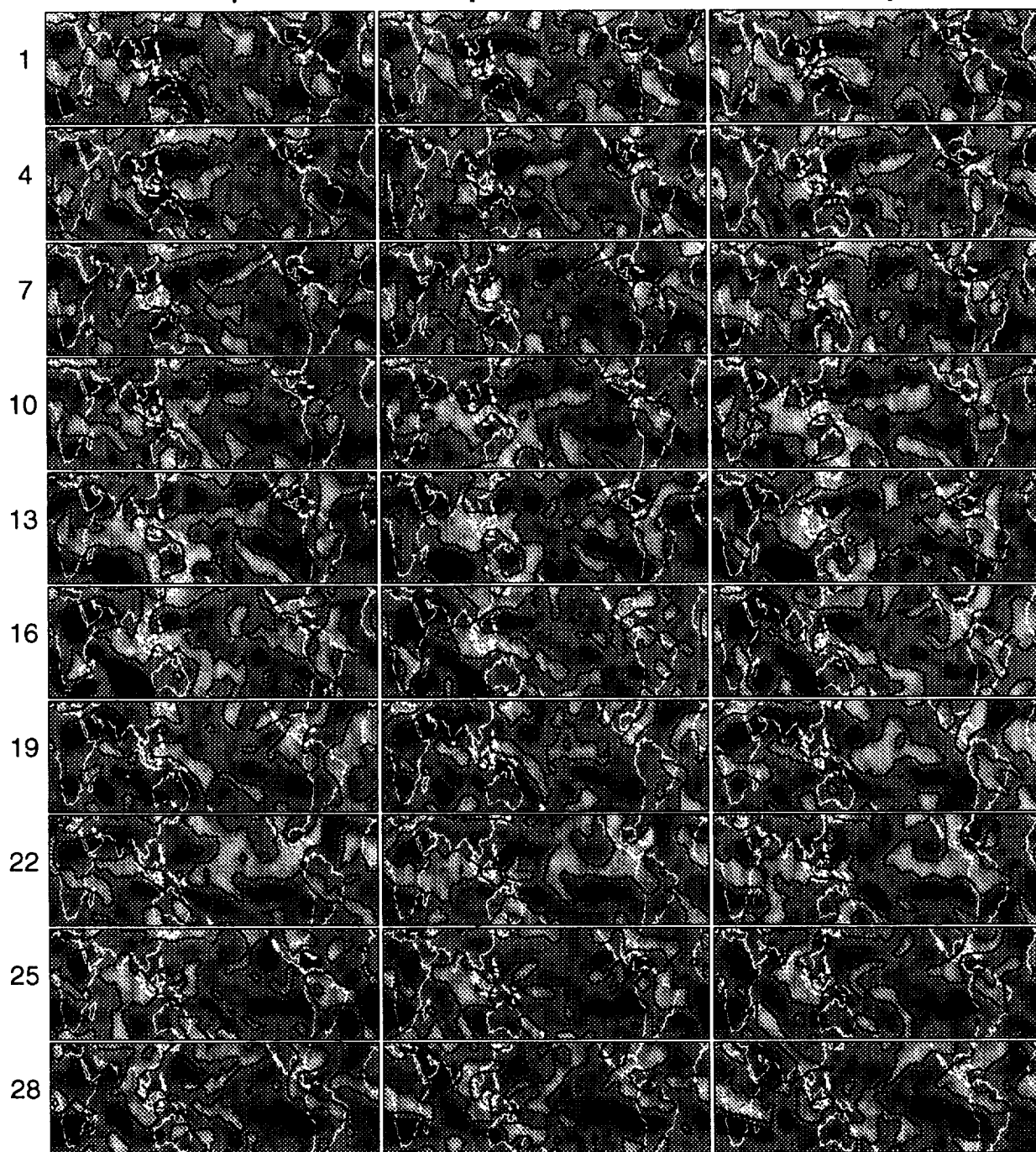
TOVS 6.5 μm Water Vapor Band

March 1979



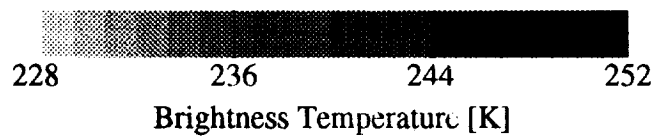
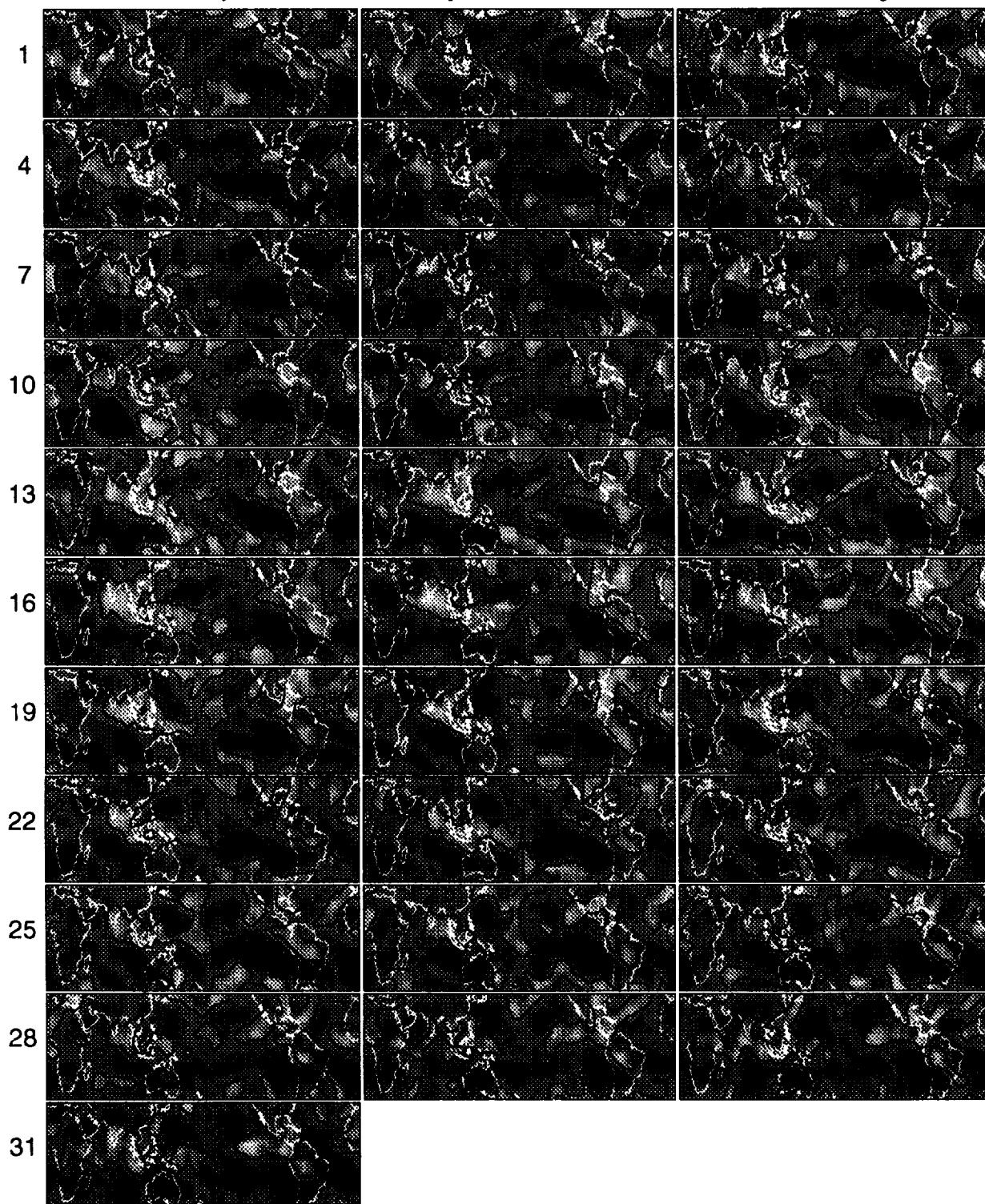
TOVS 6.5 μm Water Vapor Band

April 1979



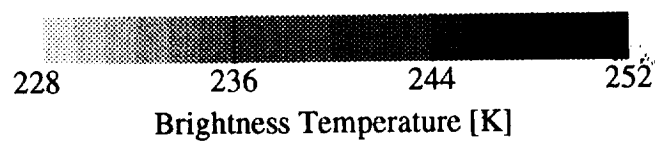
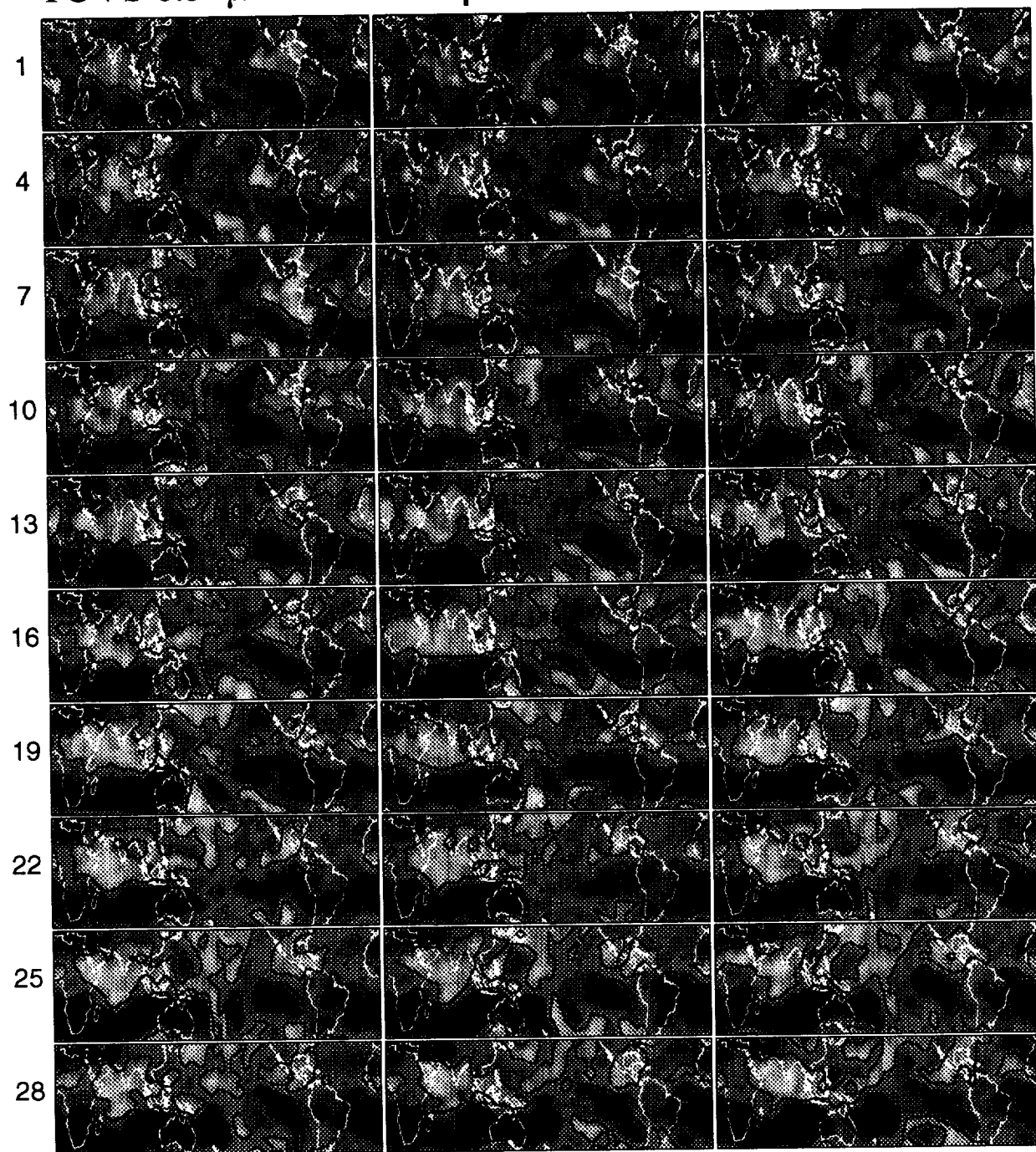
TOVS 6.5 μm Water Vapor Band

May 1979



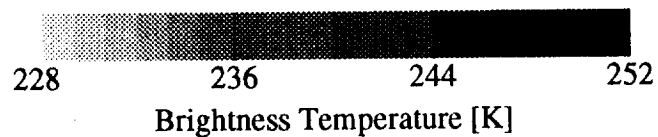
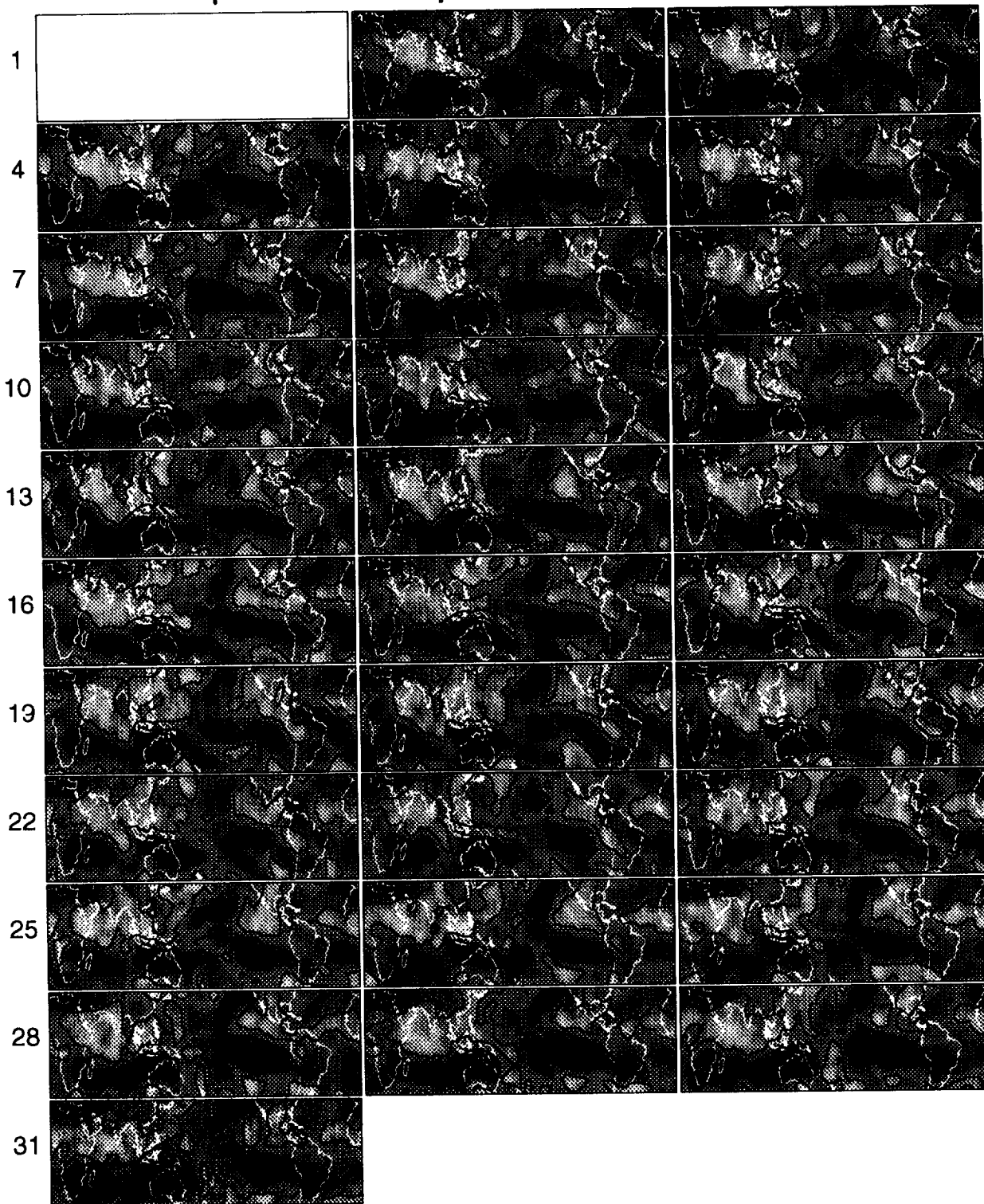
TOVS 6.5 μm Water Vapor Band

June 1979



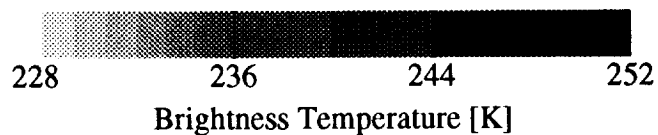
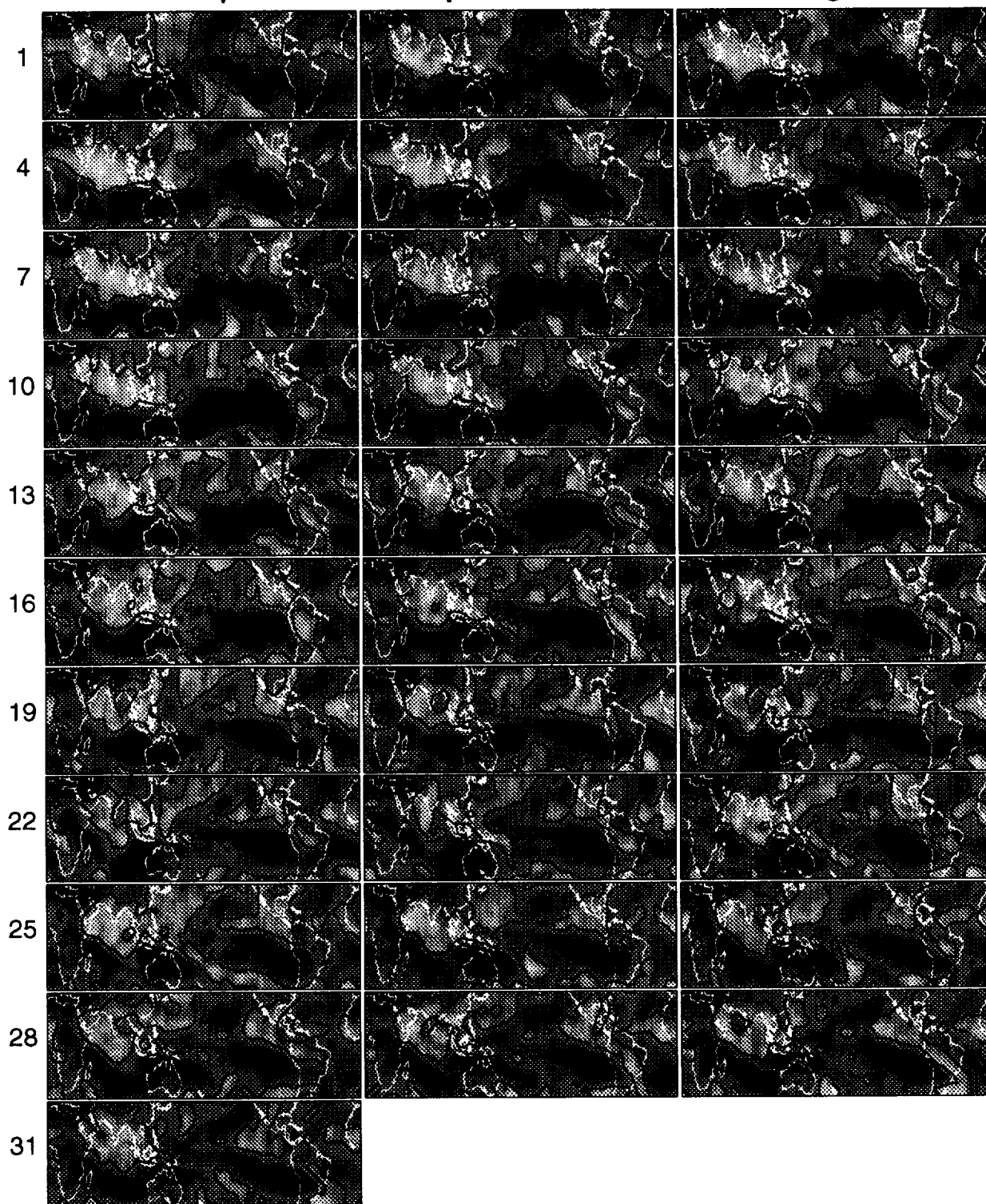
TOVS 6.5 μm Water Vapor Band

July 1979



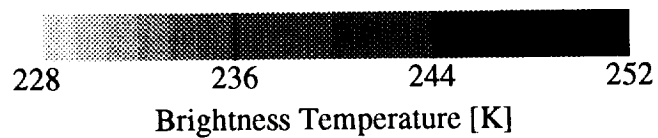
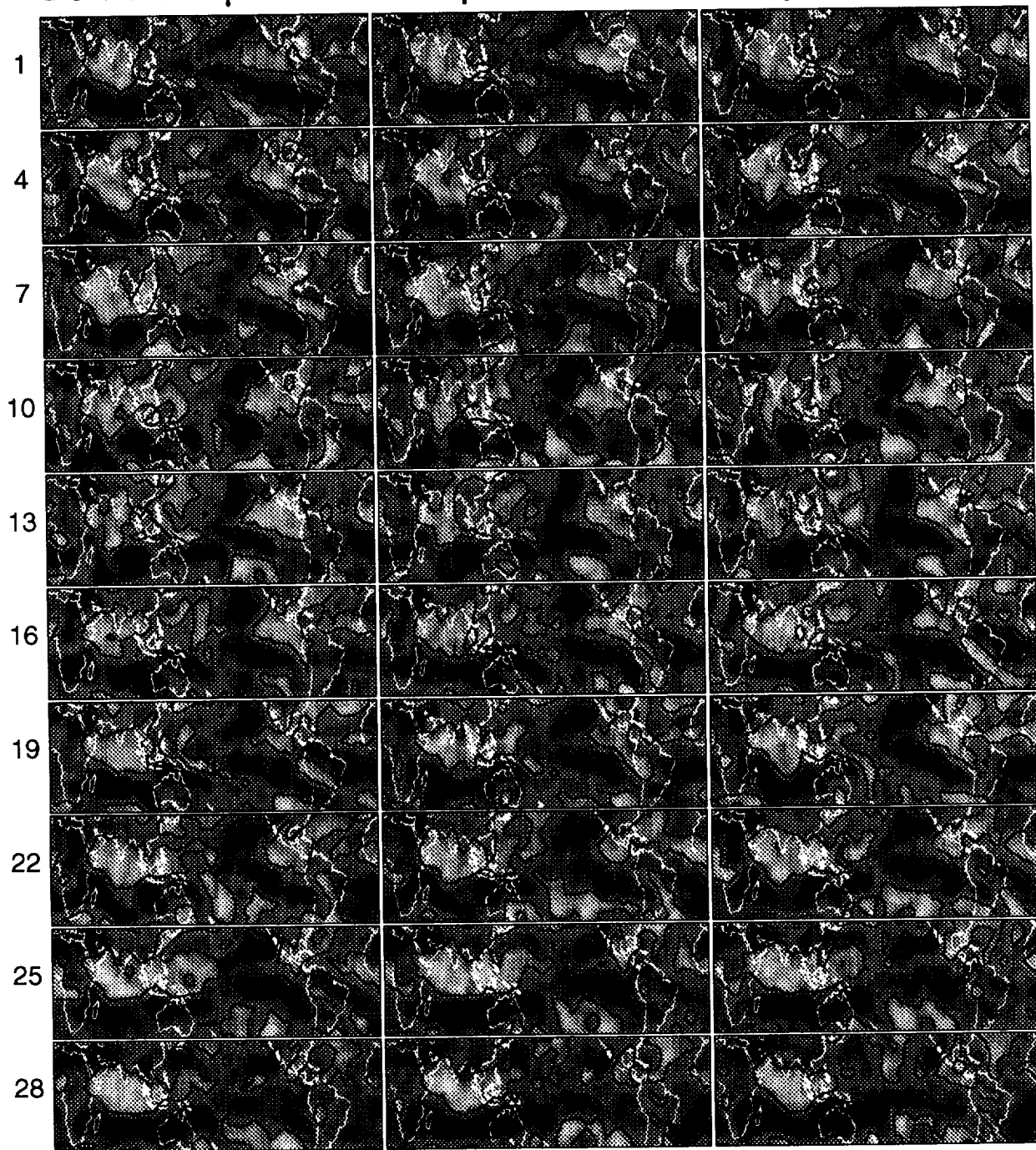
TOVS 6.5 μ m Water Vapor Band

August 1979



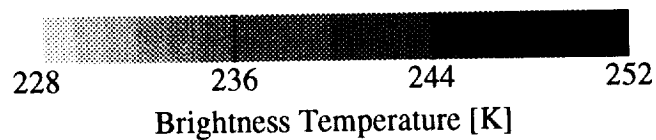
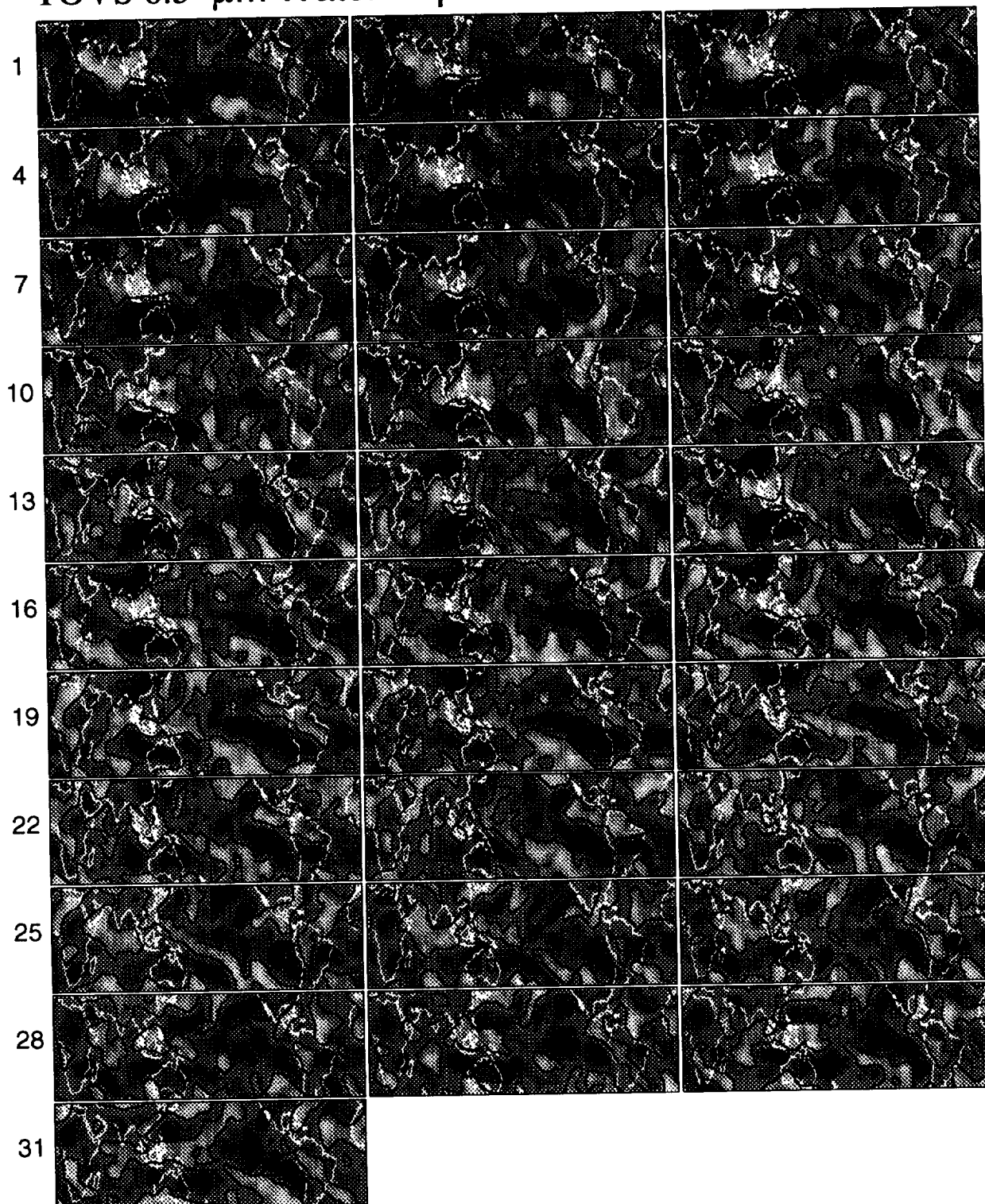
TOVS 6.5 μm Water Vapor Band

September 1979



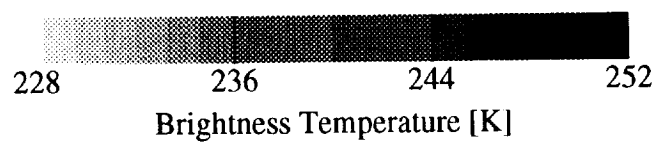
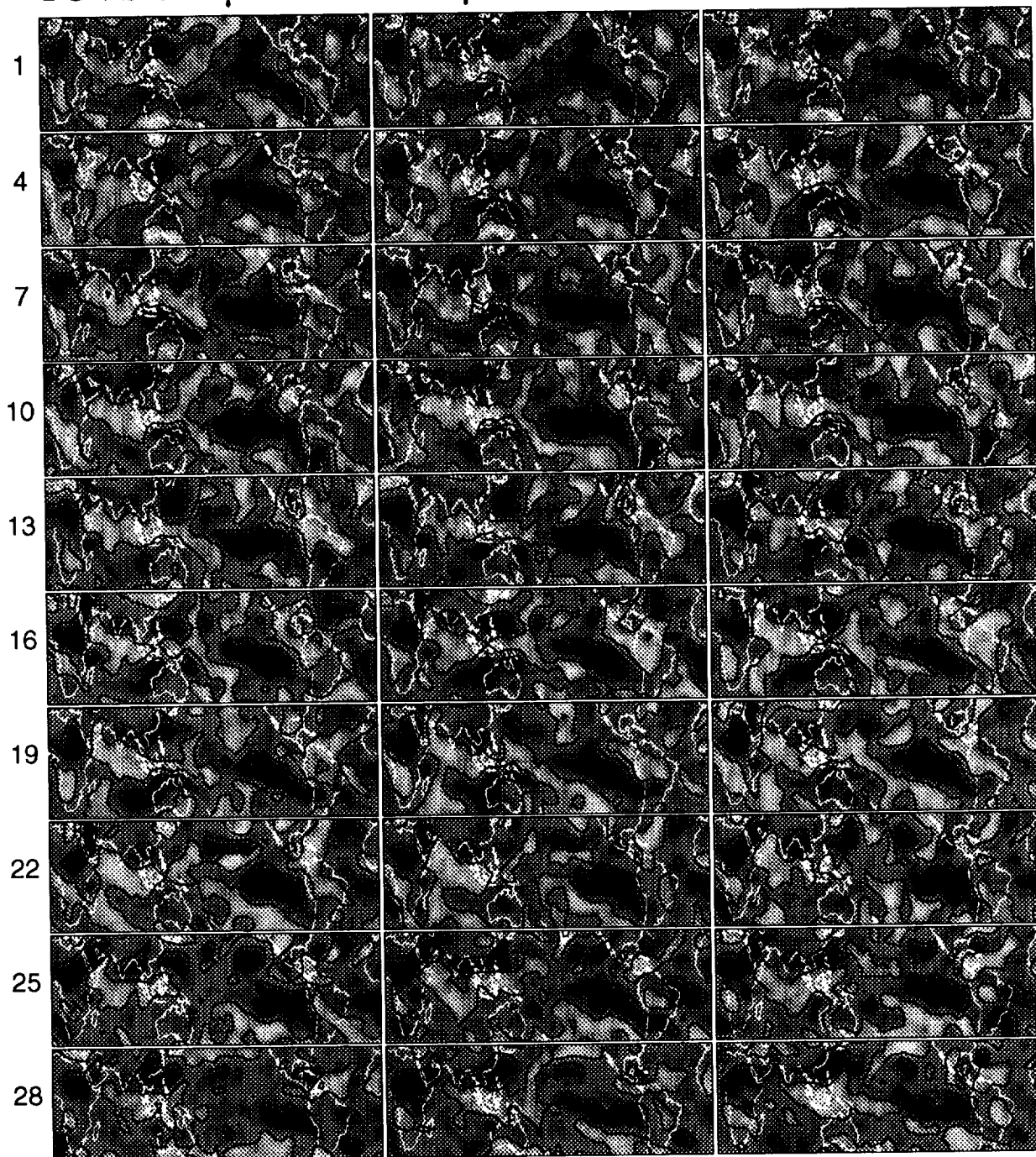
TOVS 6.5 μm Water Vapor Band

October 1979



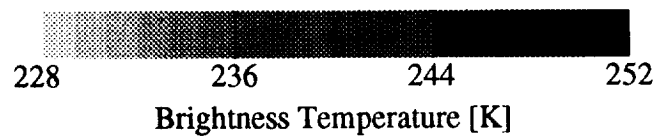
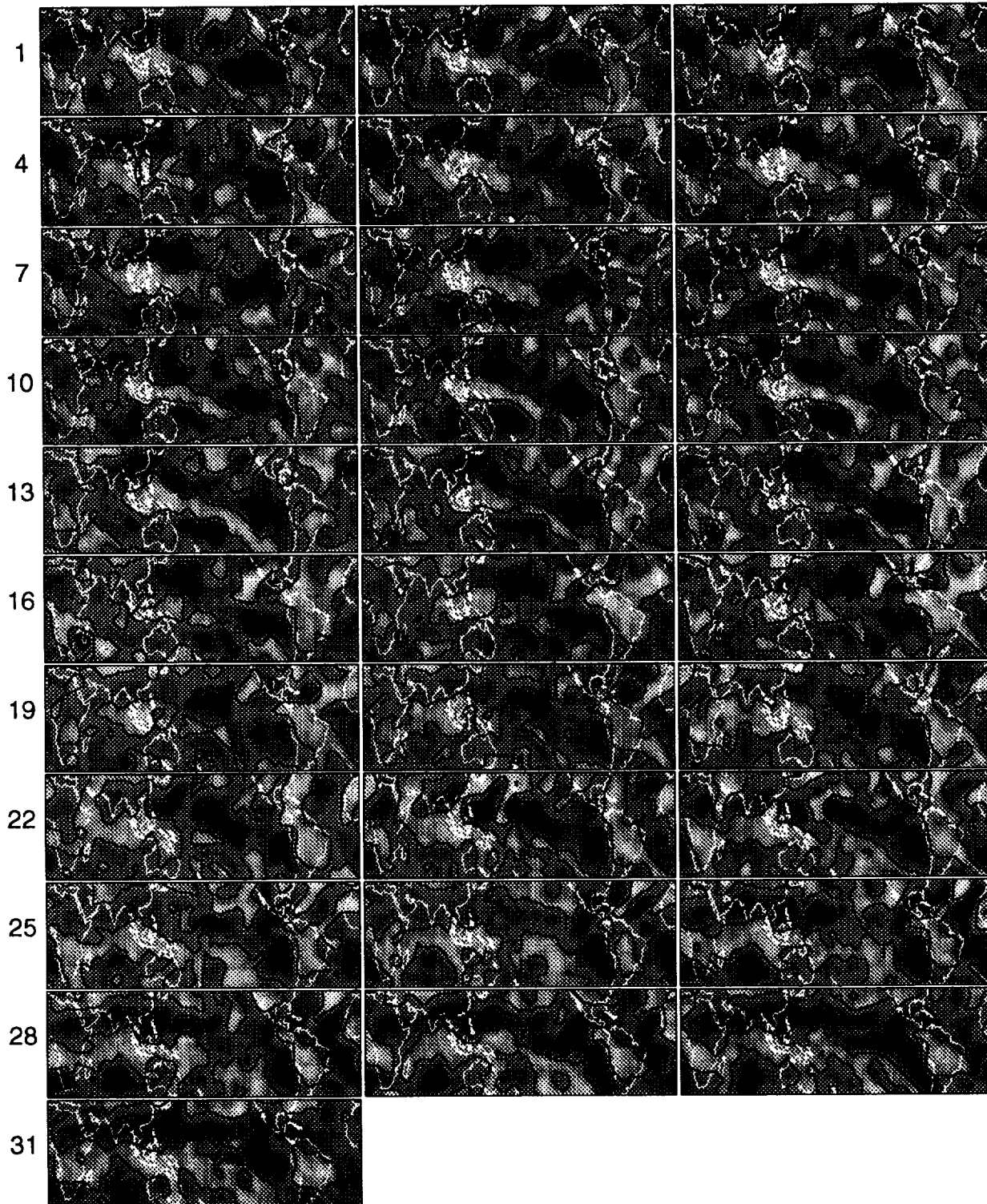
TOVS 6.5 μm Water Vapor Band

November 1979



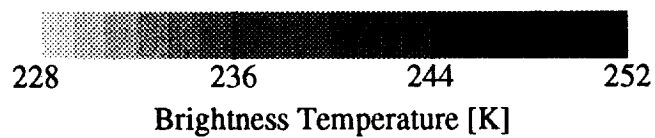
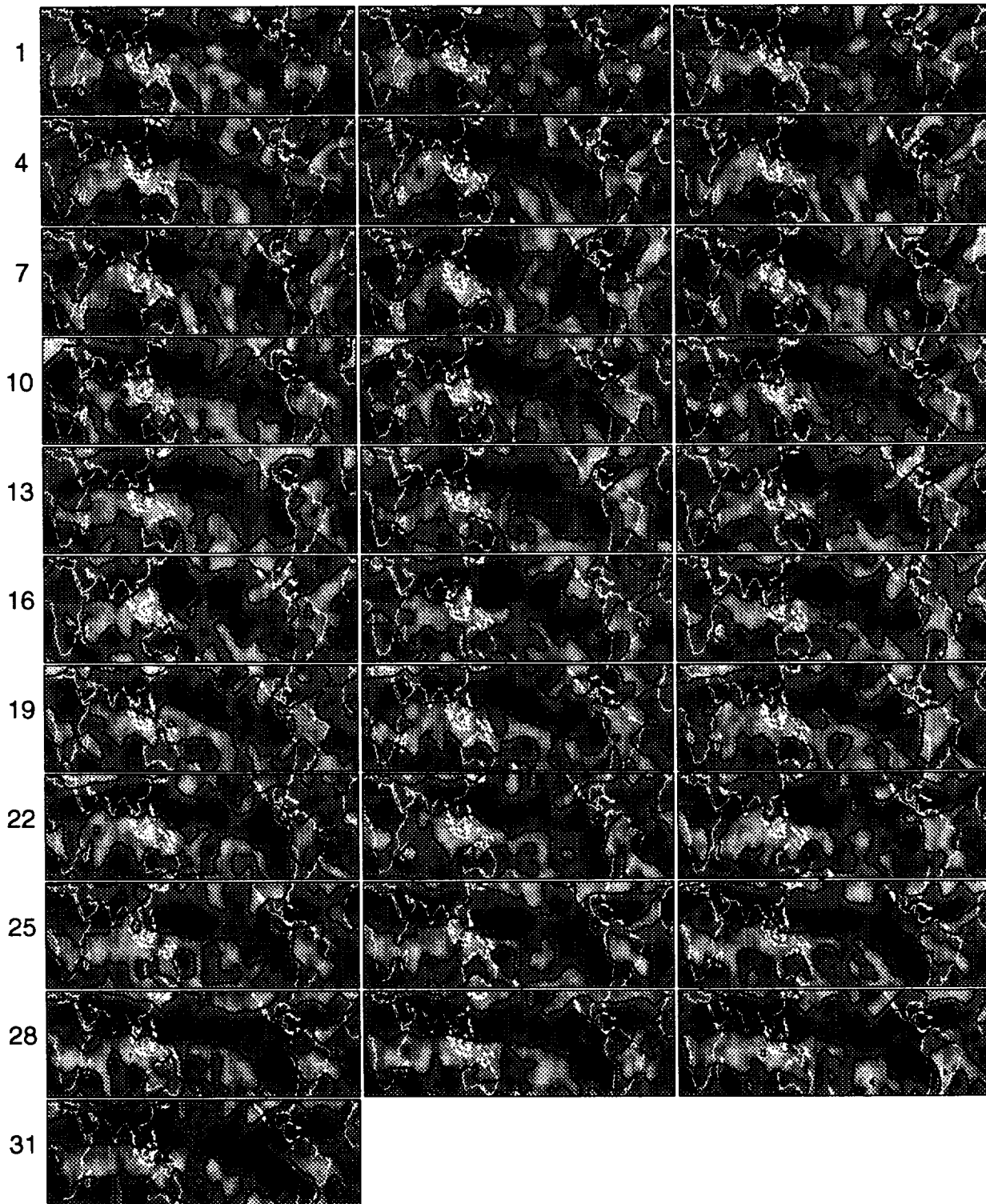
TOVS 6.5 μm Water Vapor Band

December 1979

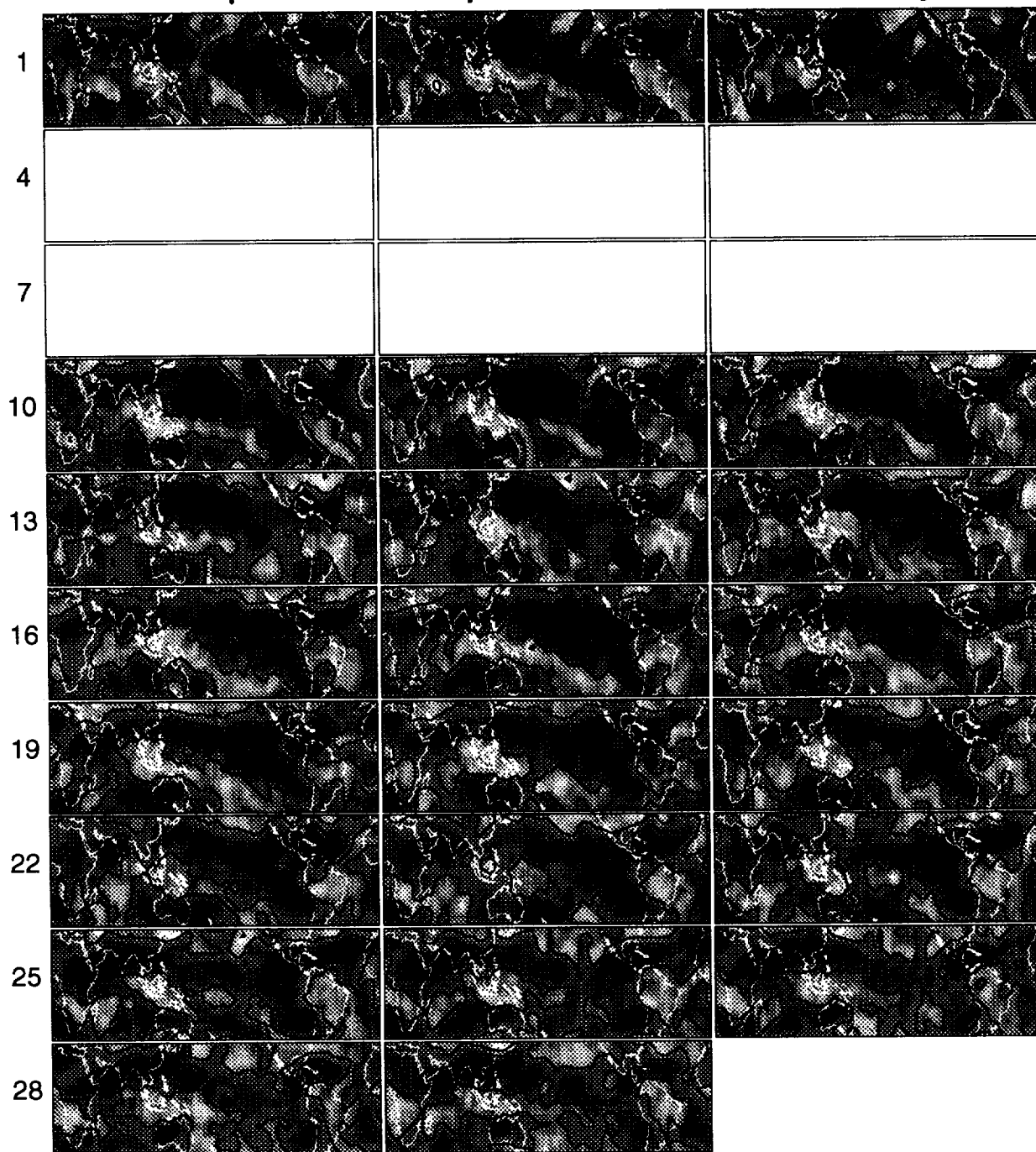


TOVS 6.5 μm Water Vapor Band

January 1980



February 1980

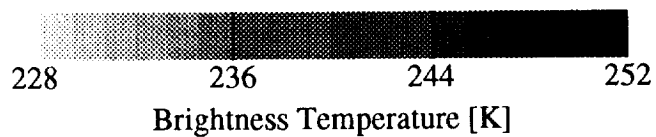
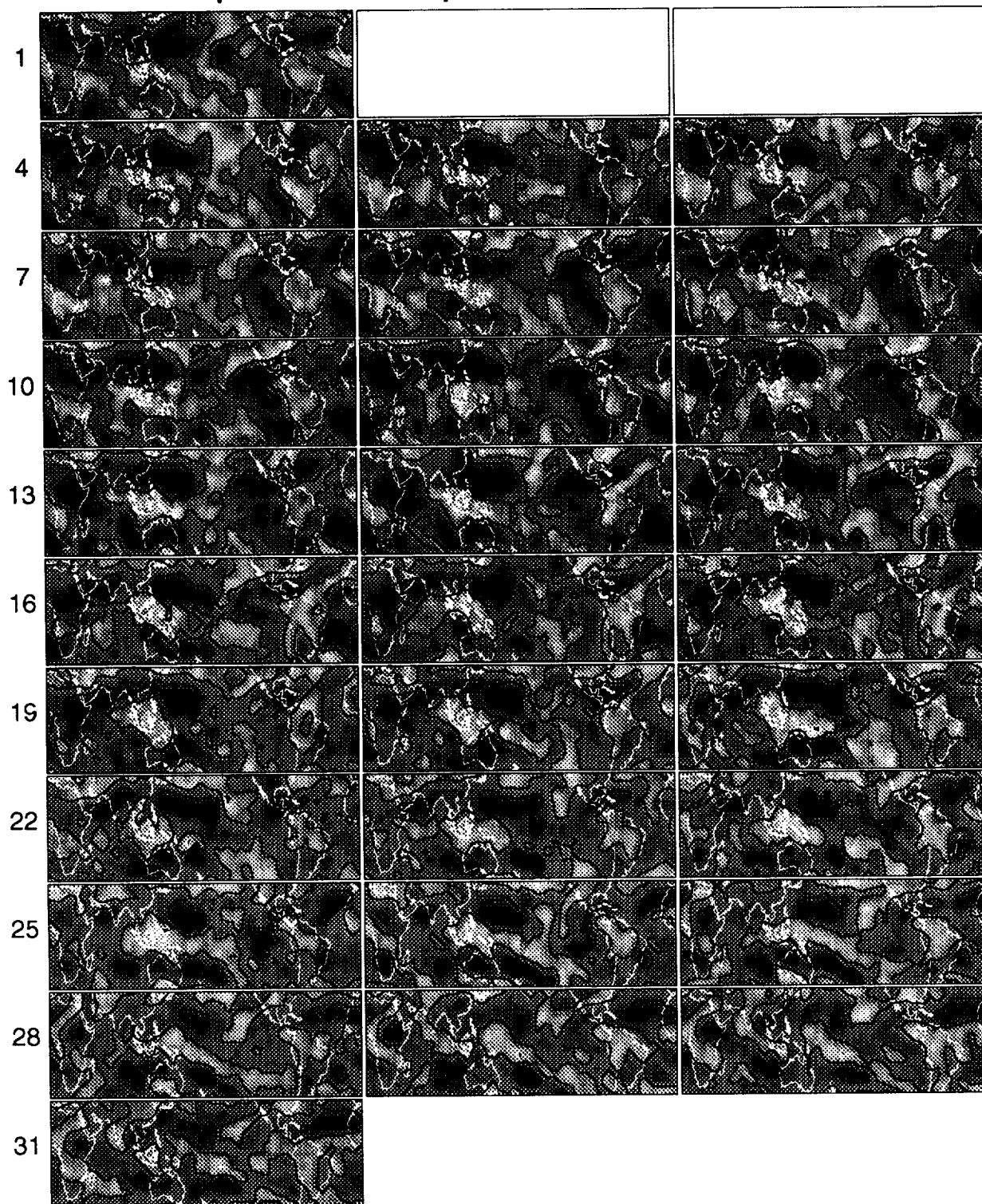


228 236 244 252

Brightness Temperature [K]

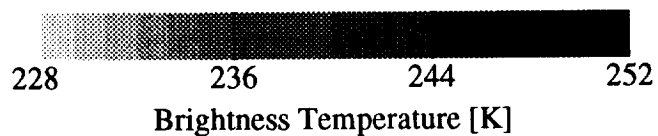
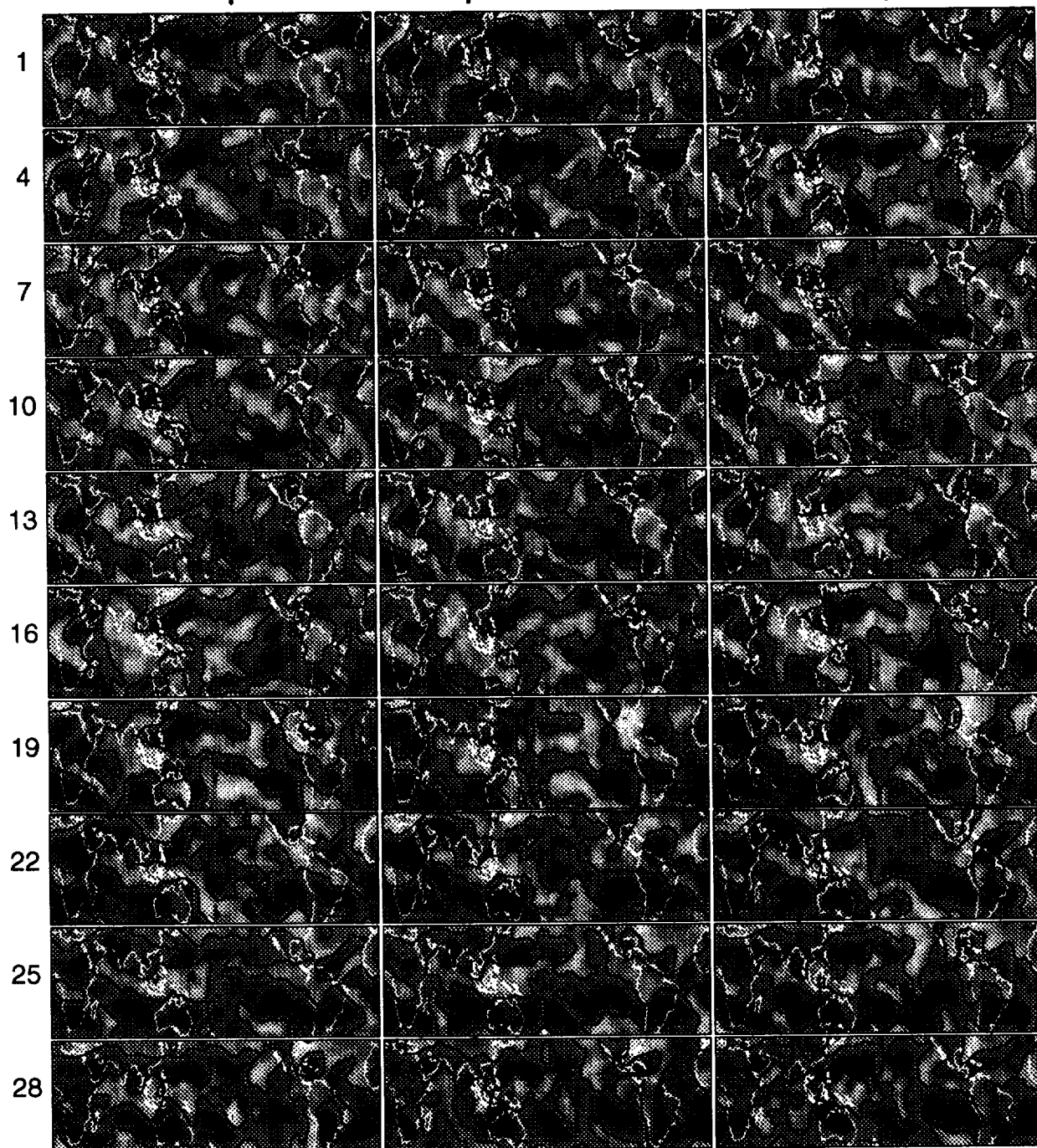
TOVS 6.5 μm Water Vapor Band

March 1980



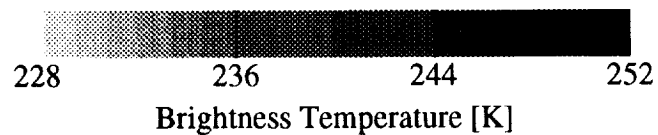
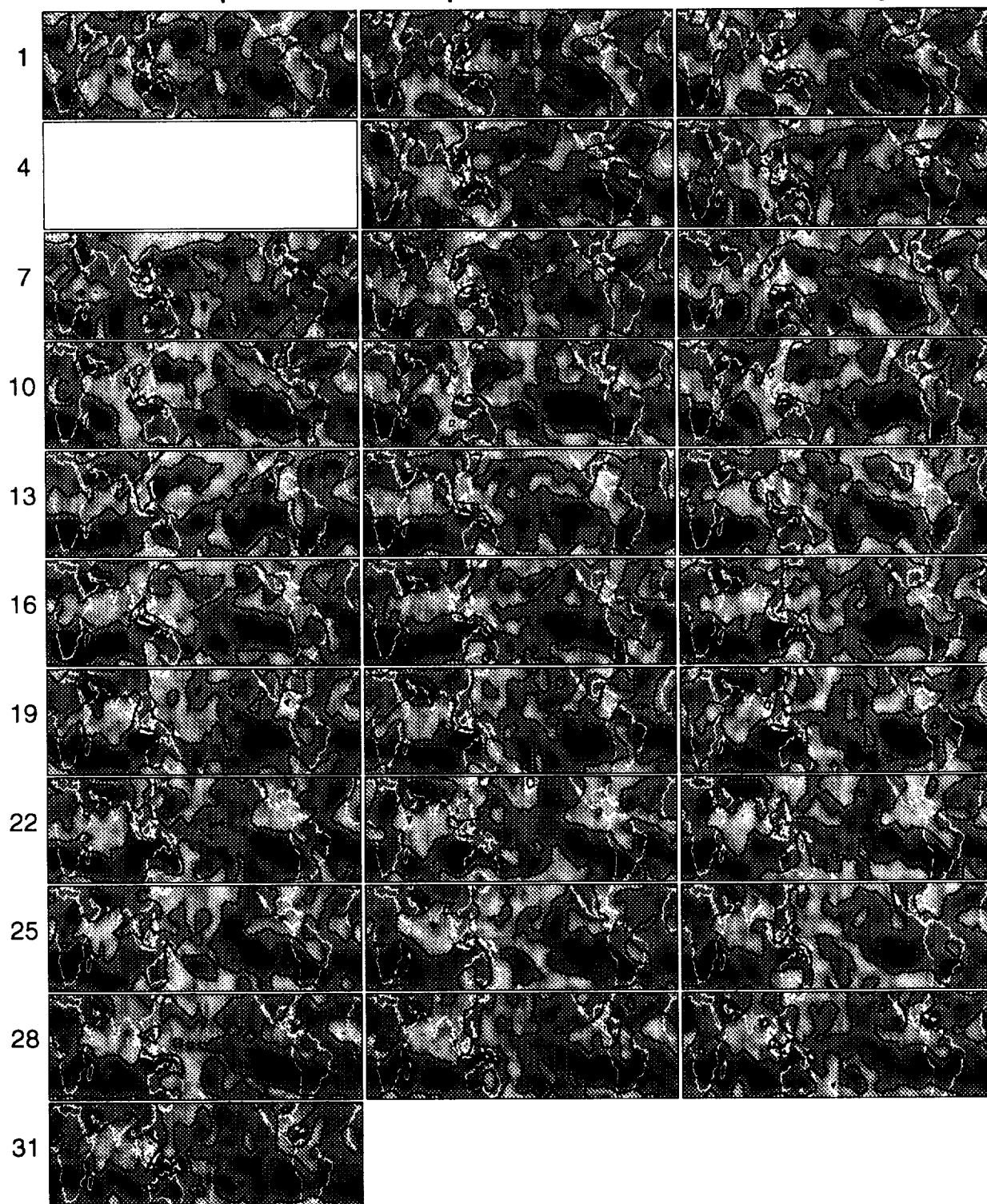
TOVS 6.5 μm Water Vapor Band

April 1980



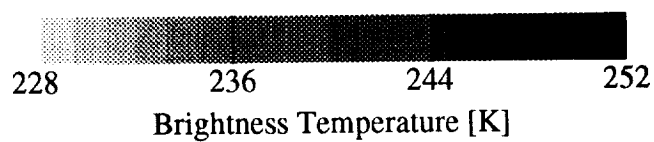
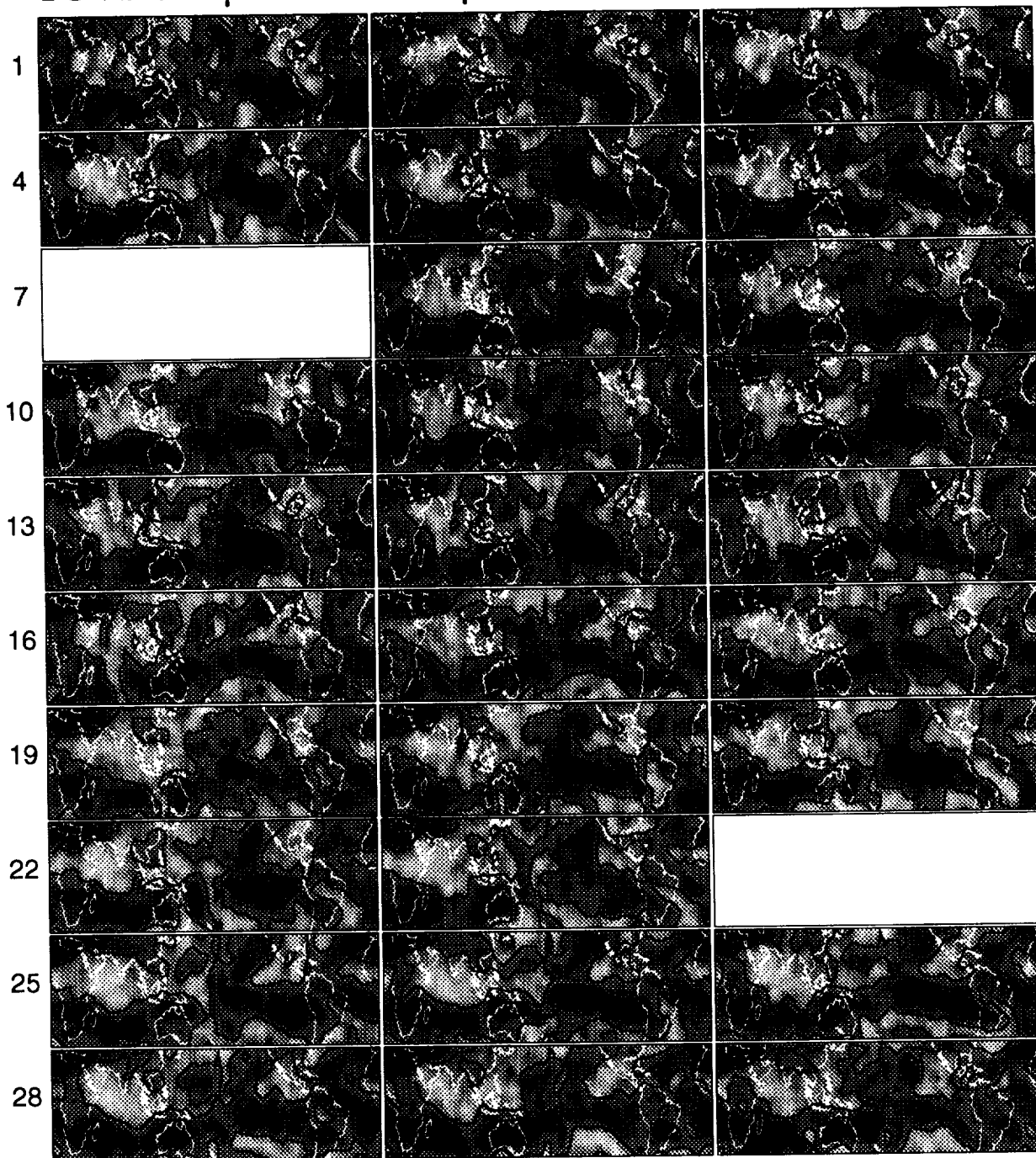
TOVS 6.5 μm Water Vapor Band

May 1980



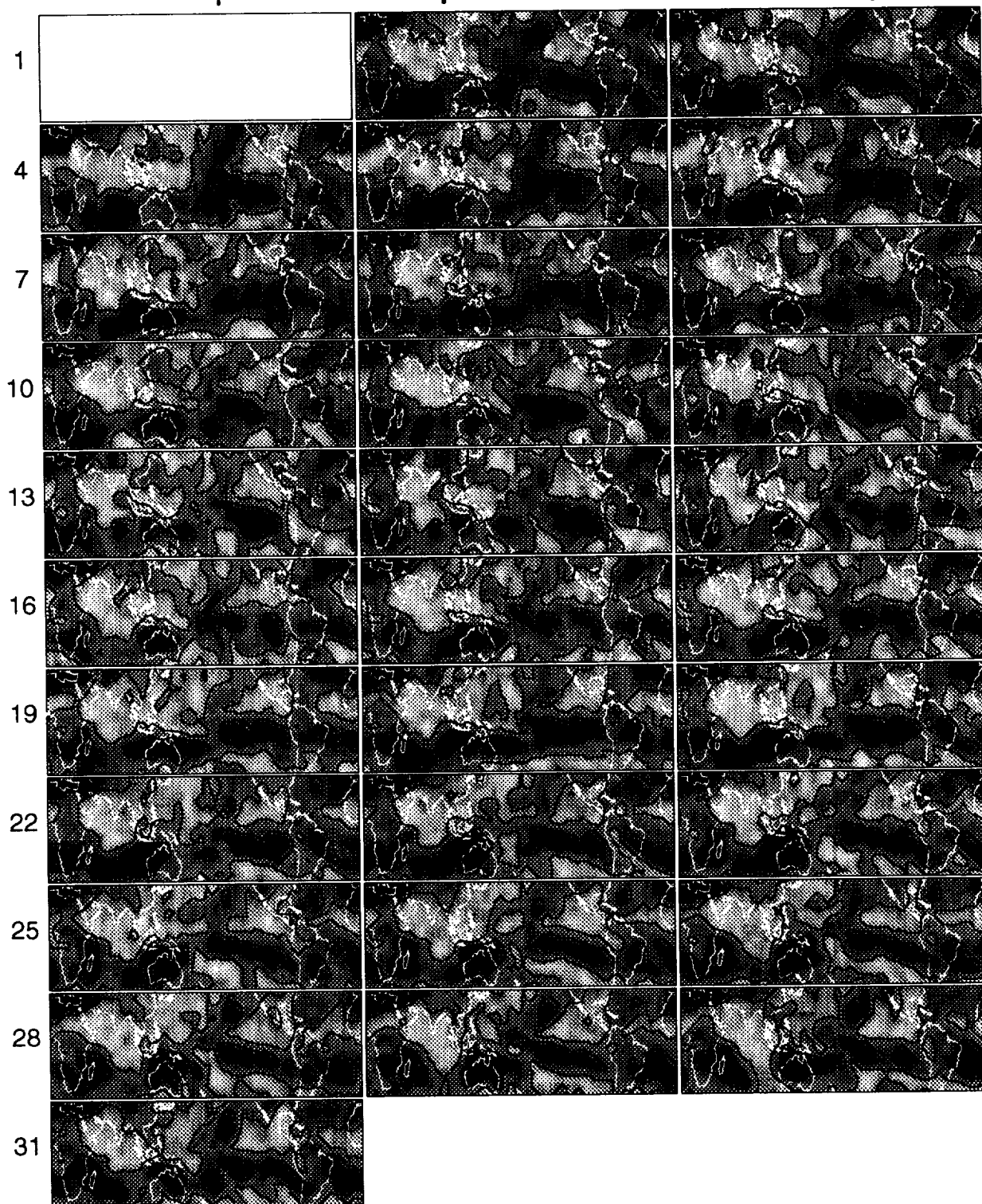
TOVS 6.5 μm Water Vapor Band

June 1980



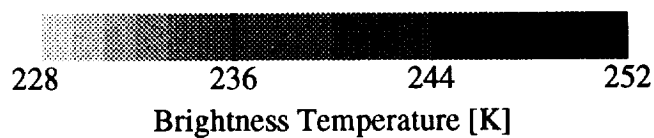
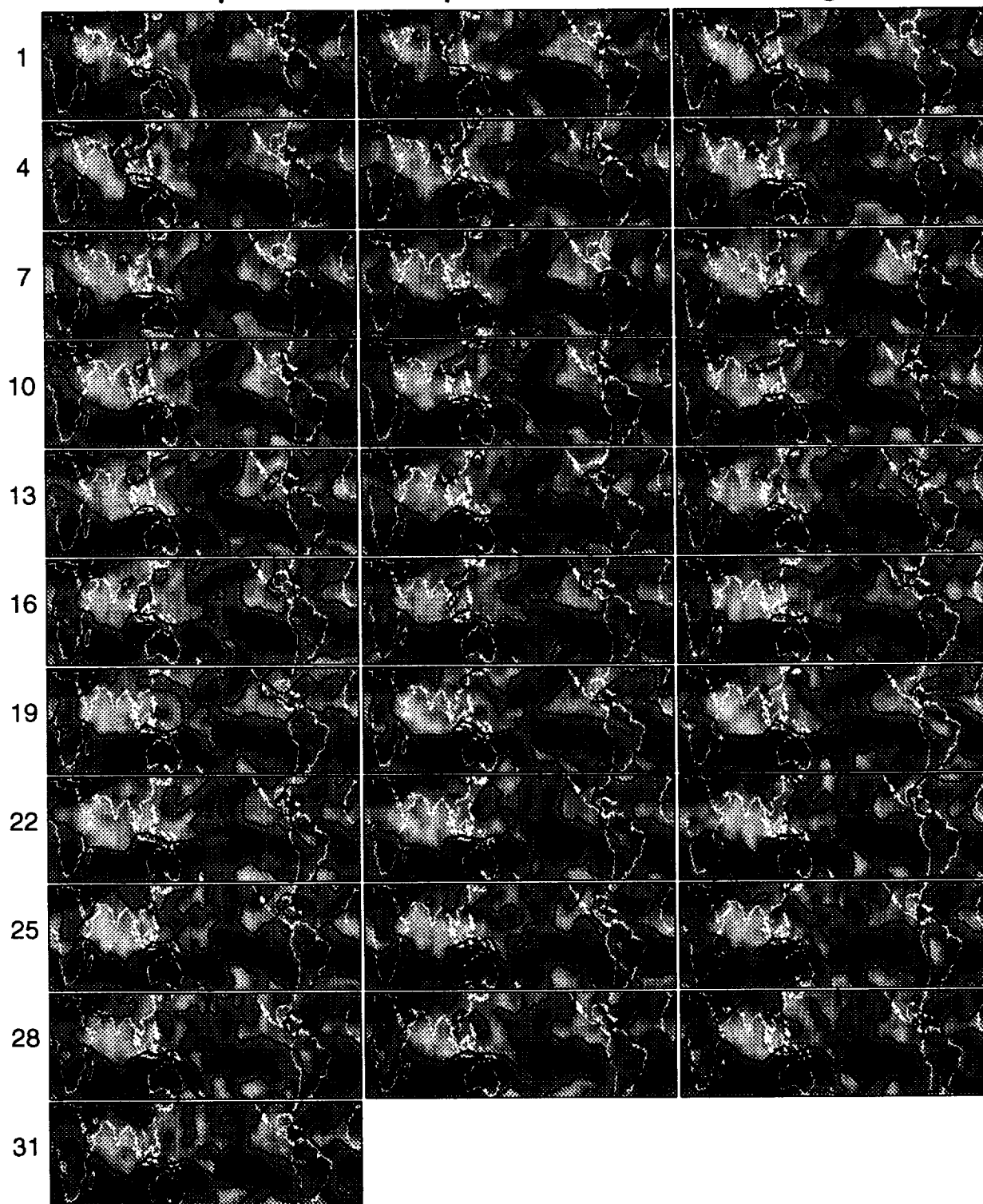
TOVS 6.5 μm Water Vapor Band

July 1980



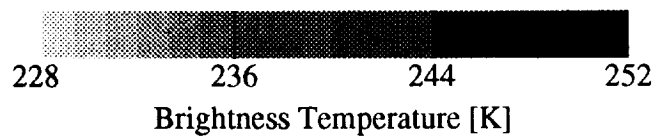
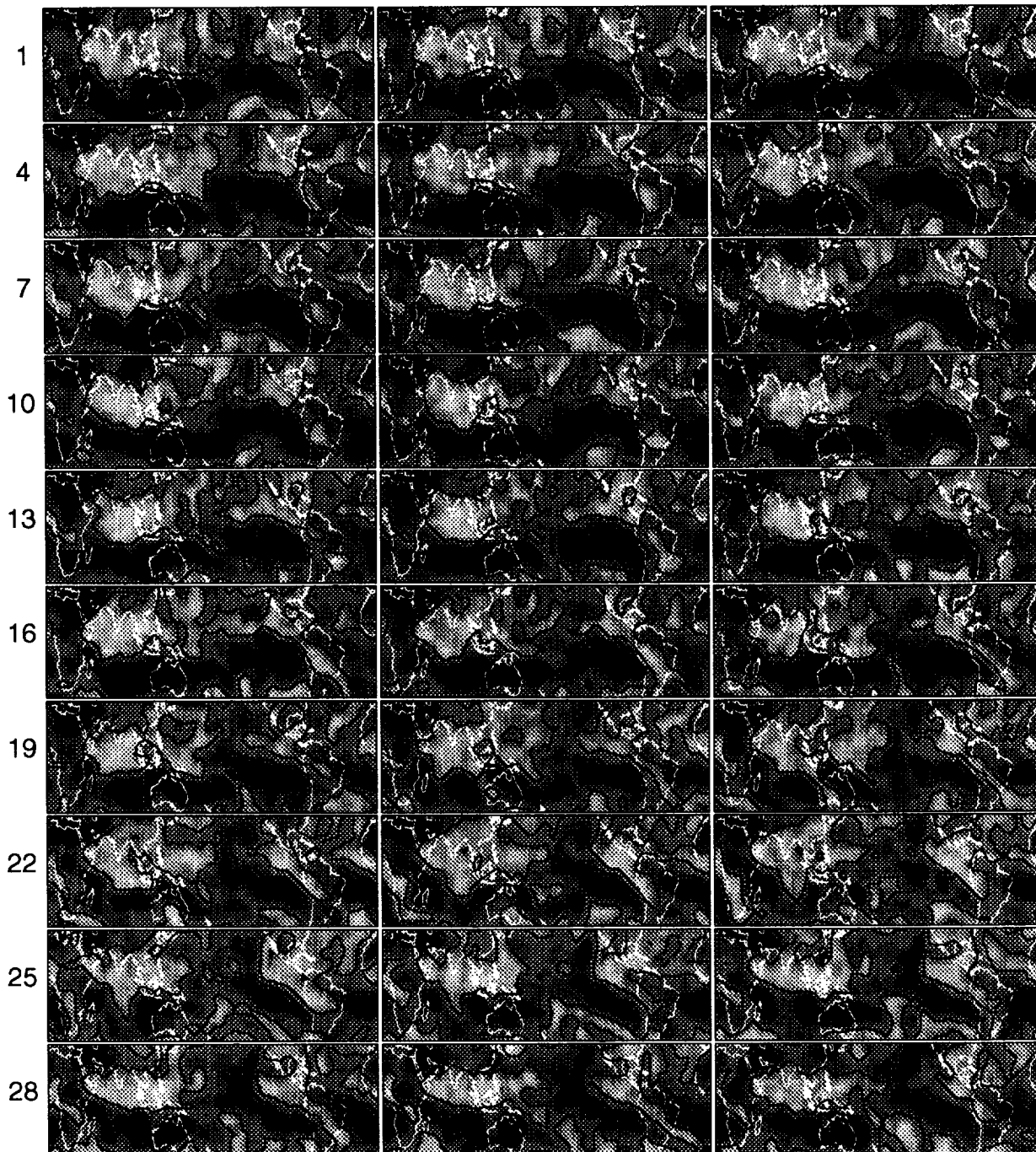
TOVS 6.5 μm Water Vapor Band

August 1980



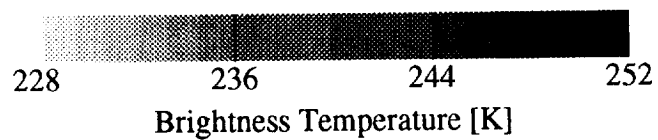
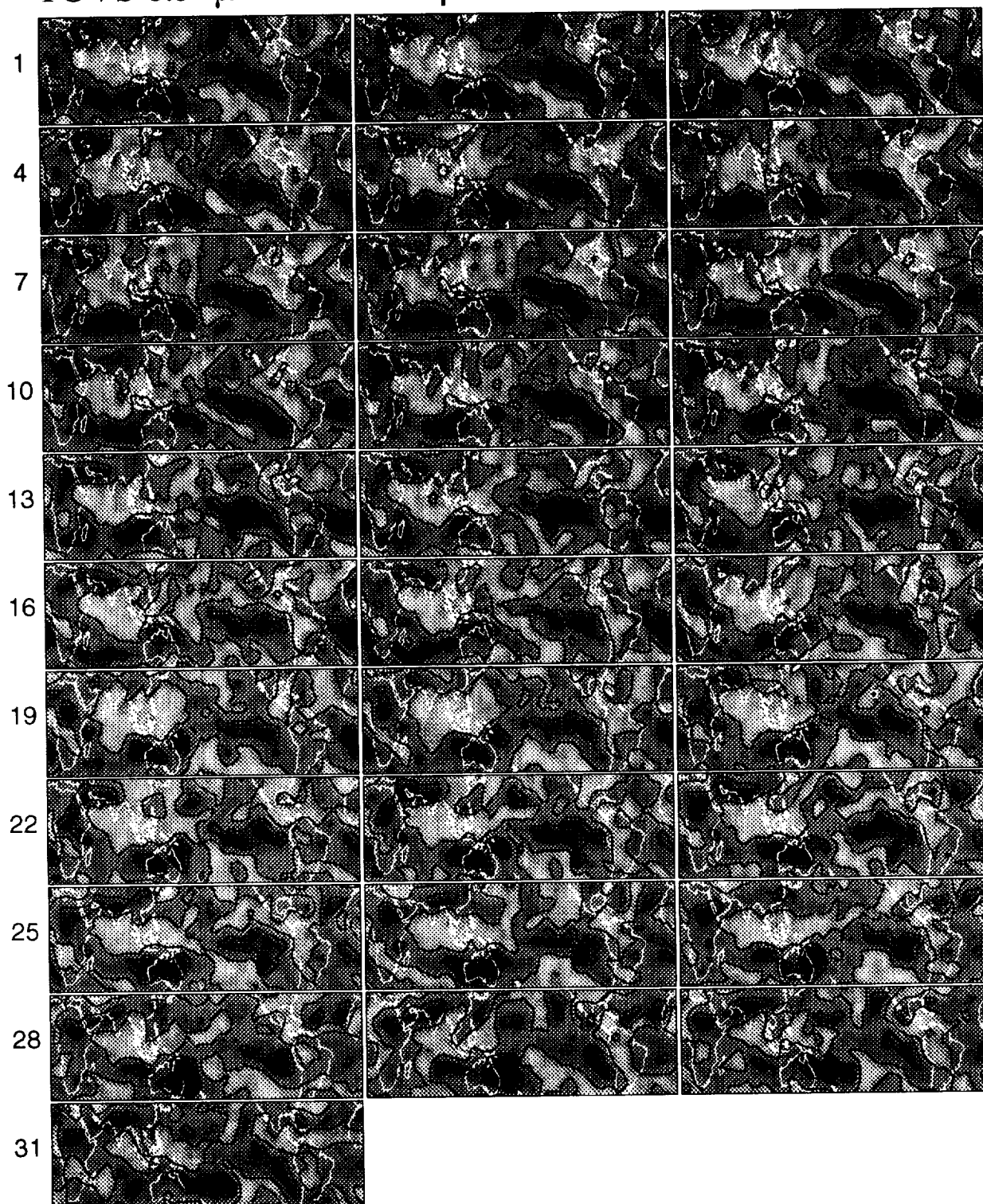
TOVS 6.5 μm Water Vapor Band

September 1980



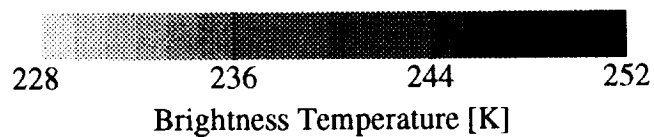
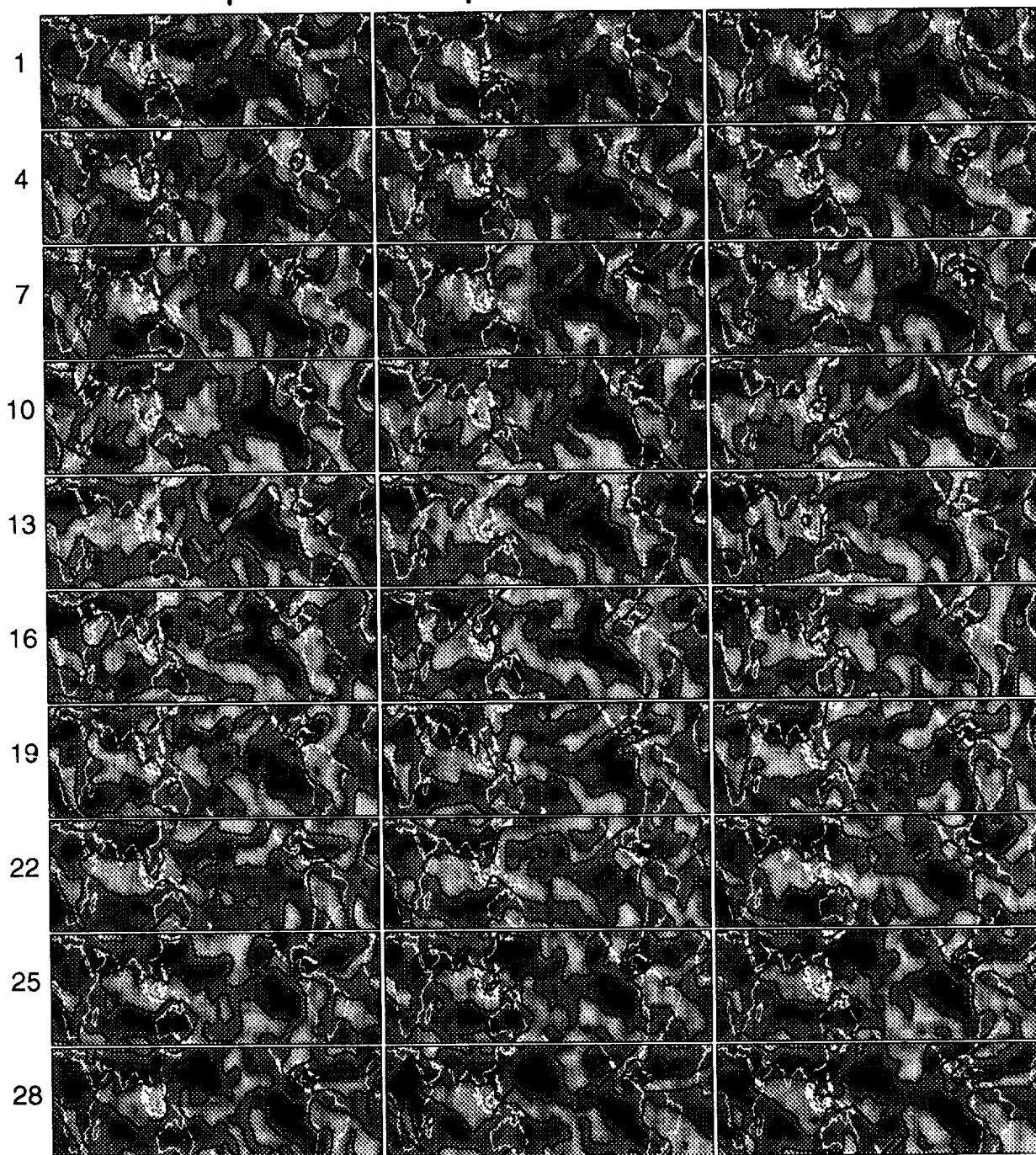
TOVS 6.5 μm Water Vapor Band

October 1980



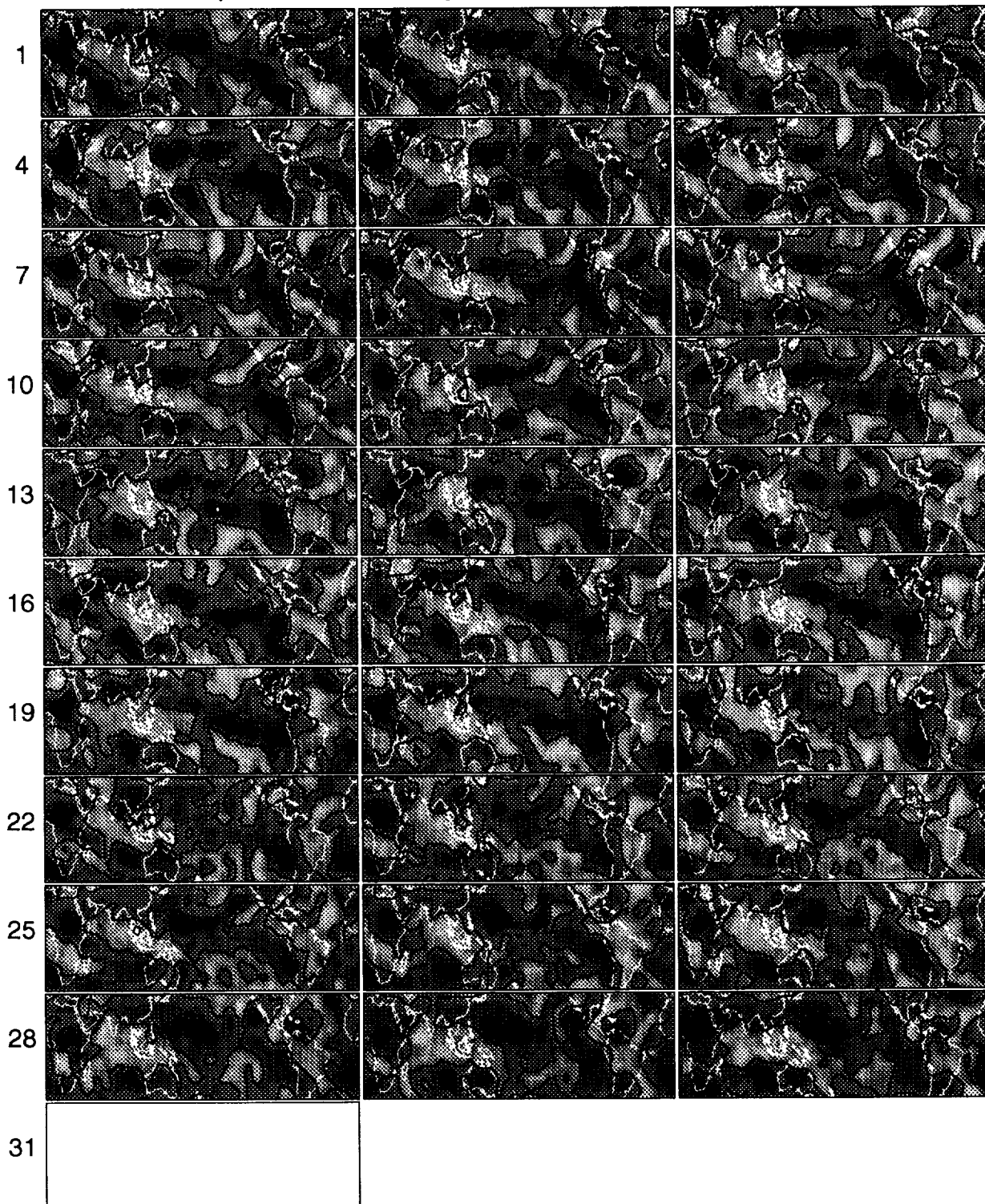
TOVS 6.5 μm Water Vapor Band

November 1980



TOVS 6.5 μm Water Vapor Band

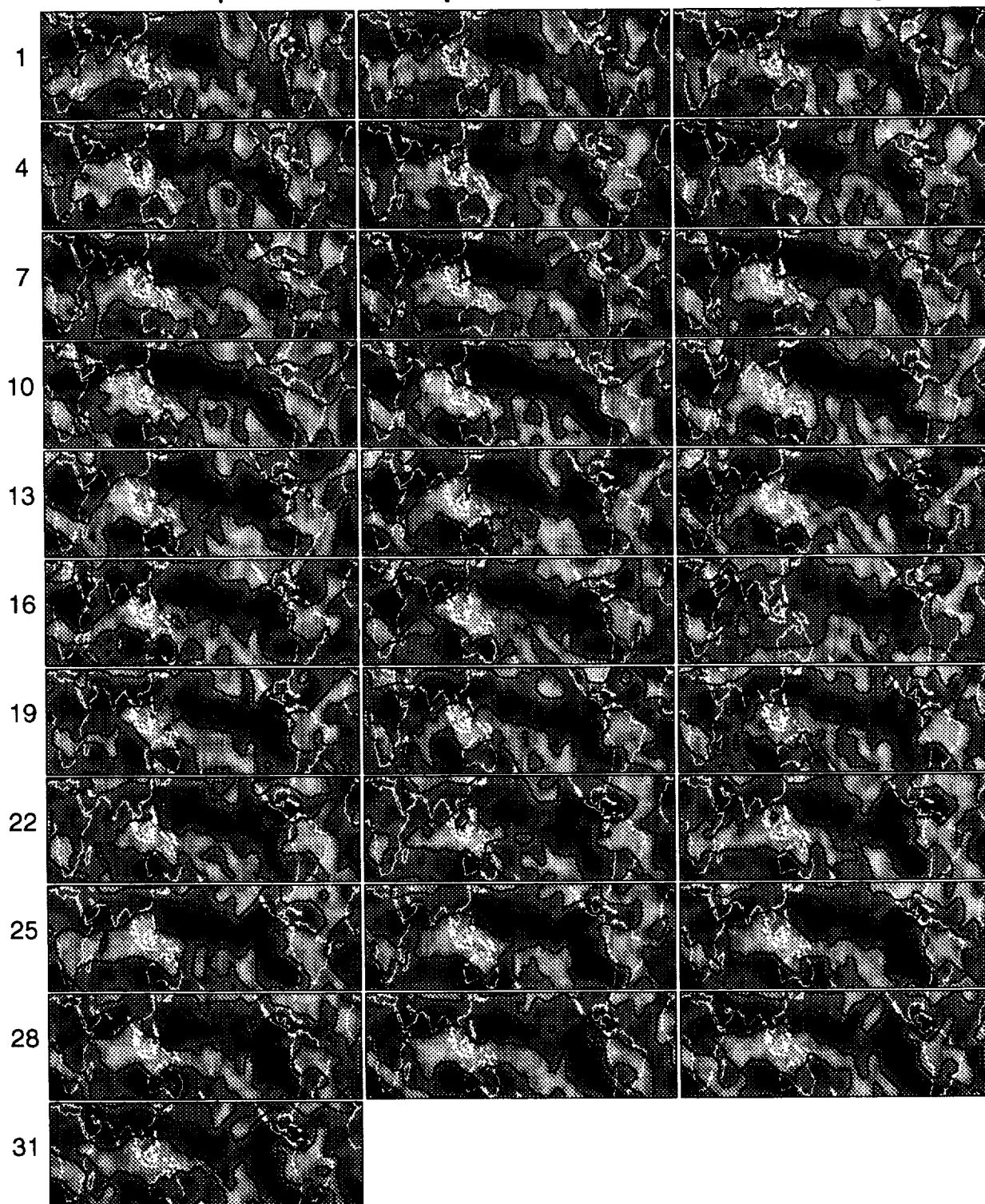
December 1980



228 236 244 252
Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

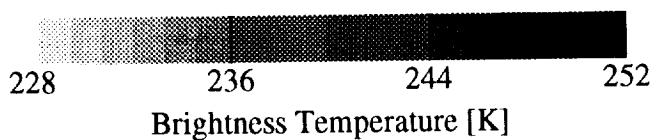
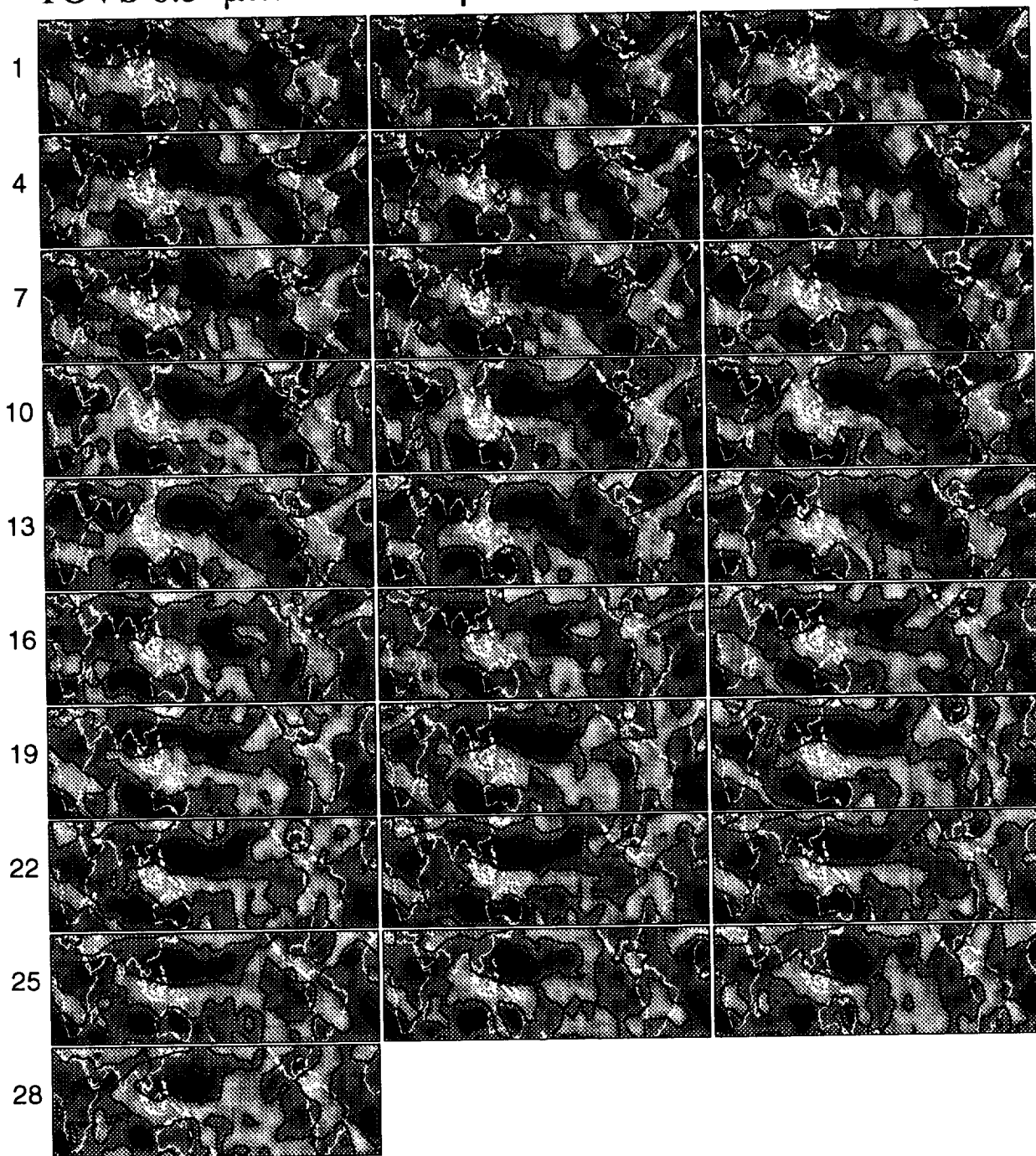
January 1981



228 236 244 252
Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

February 1981



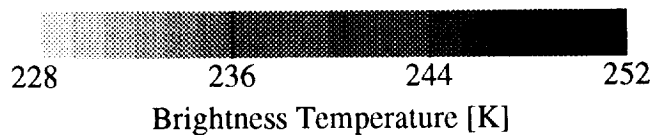
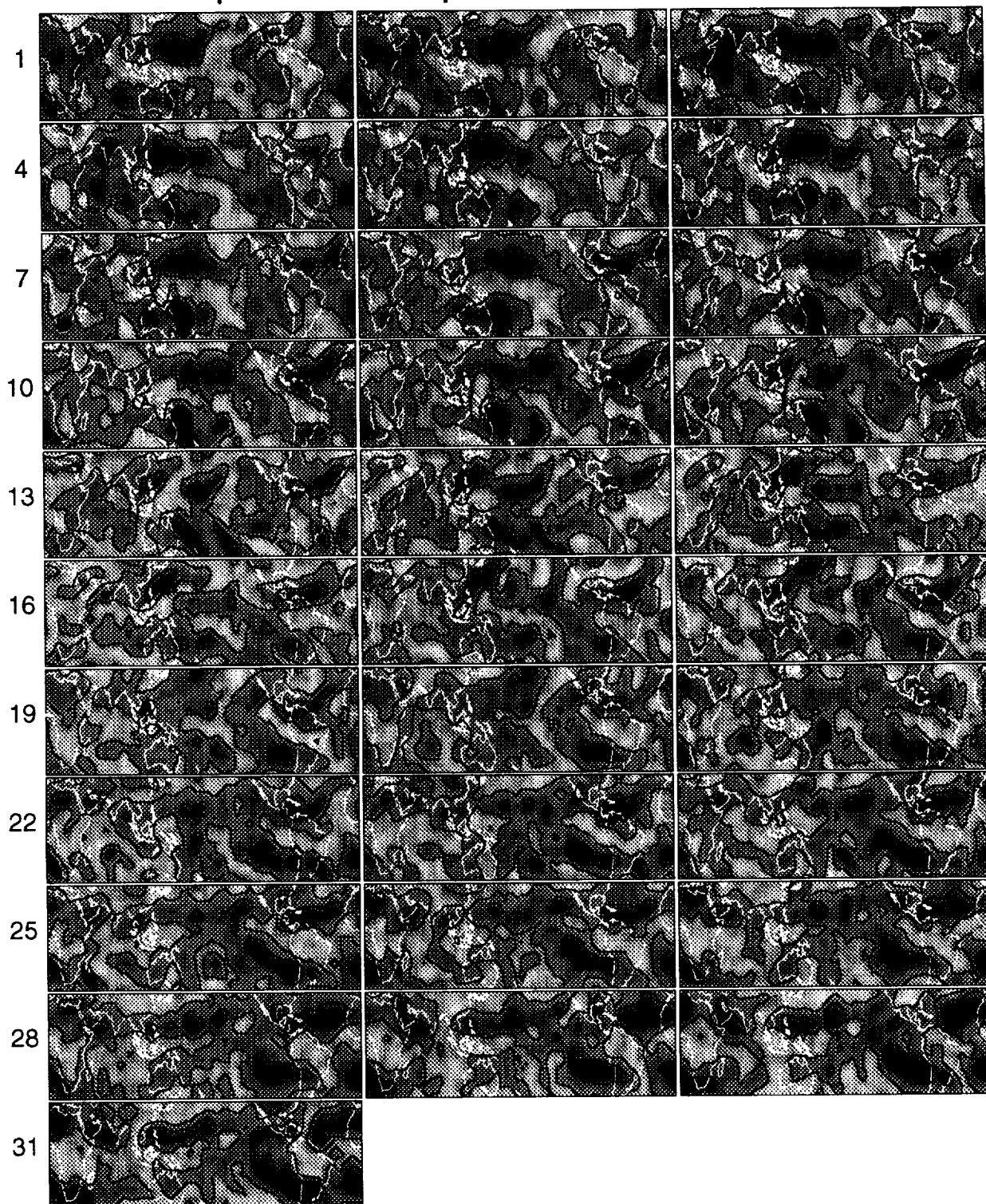
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A-53

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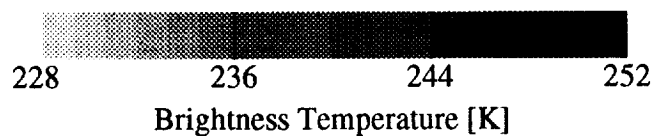
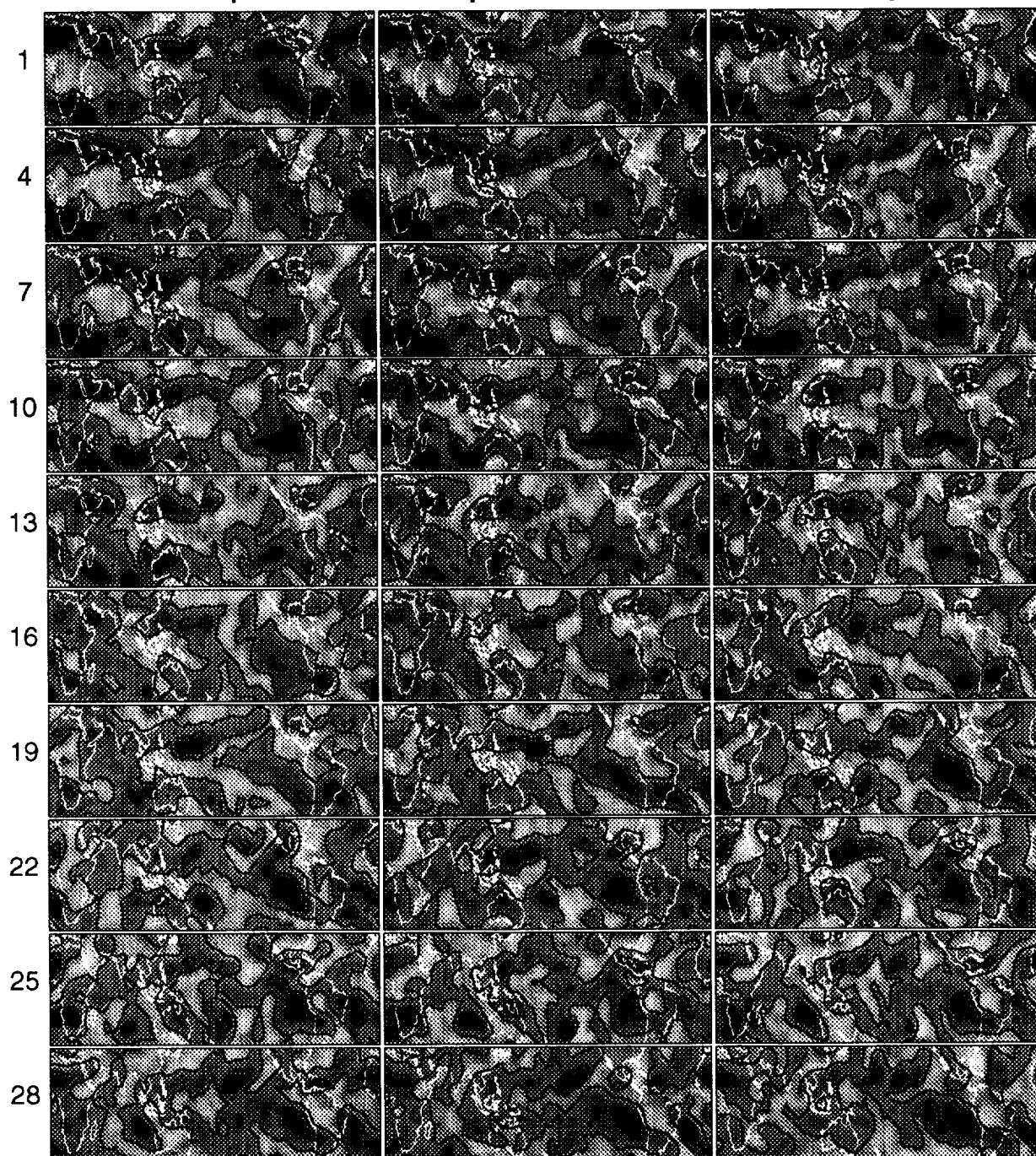
TOVS 6.5 μm Water Vapor Band

March 1981



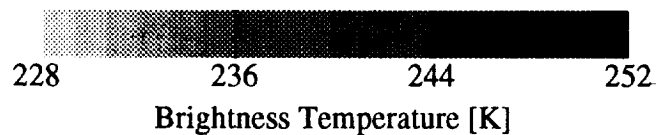
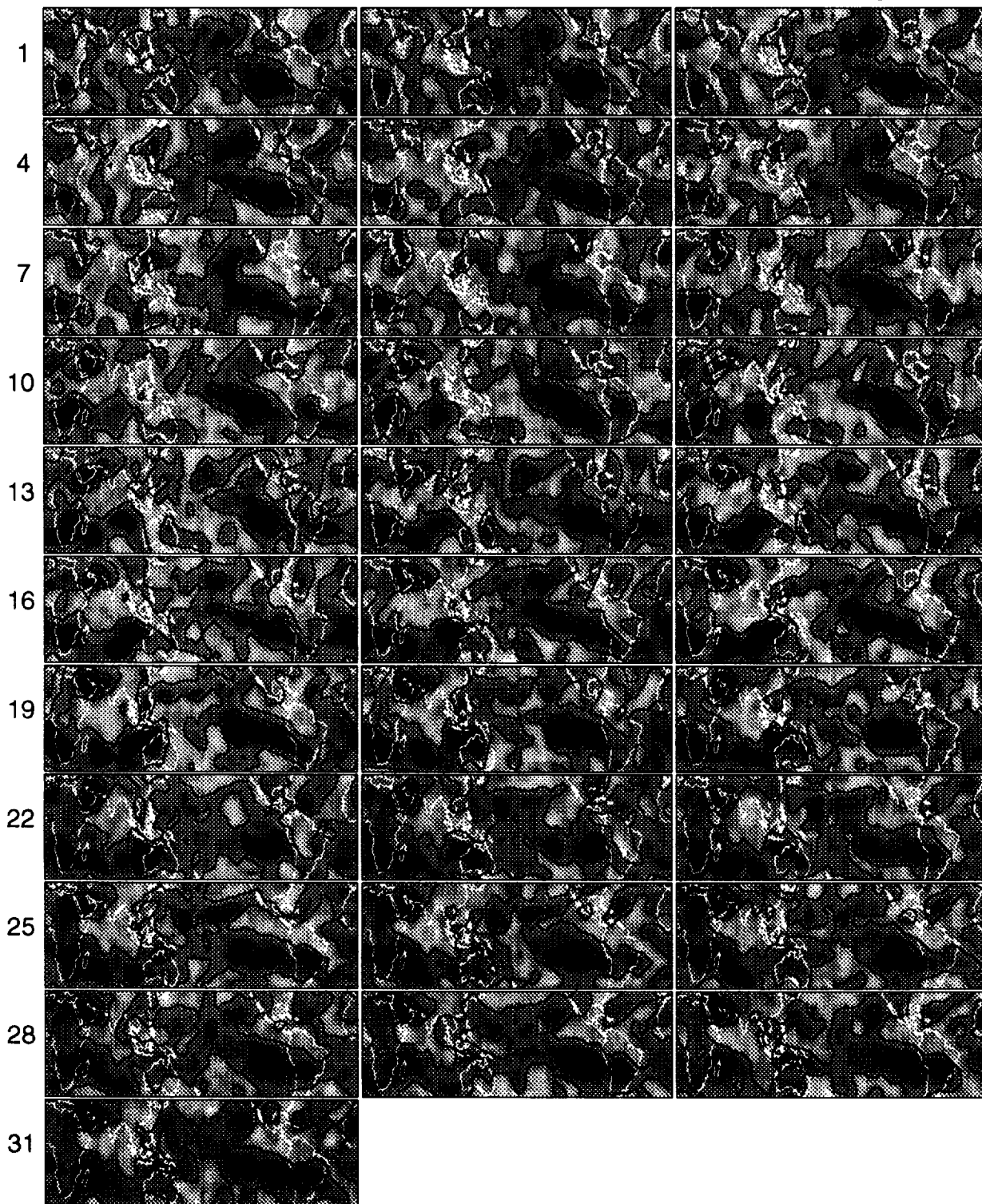
TOVS 6.5 μm Water Vapor Band

April 1981



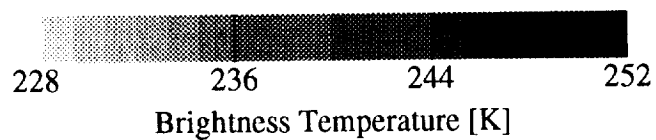
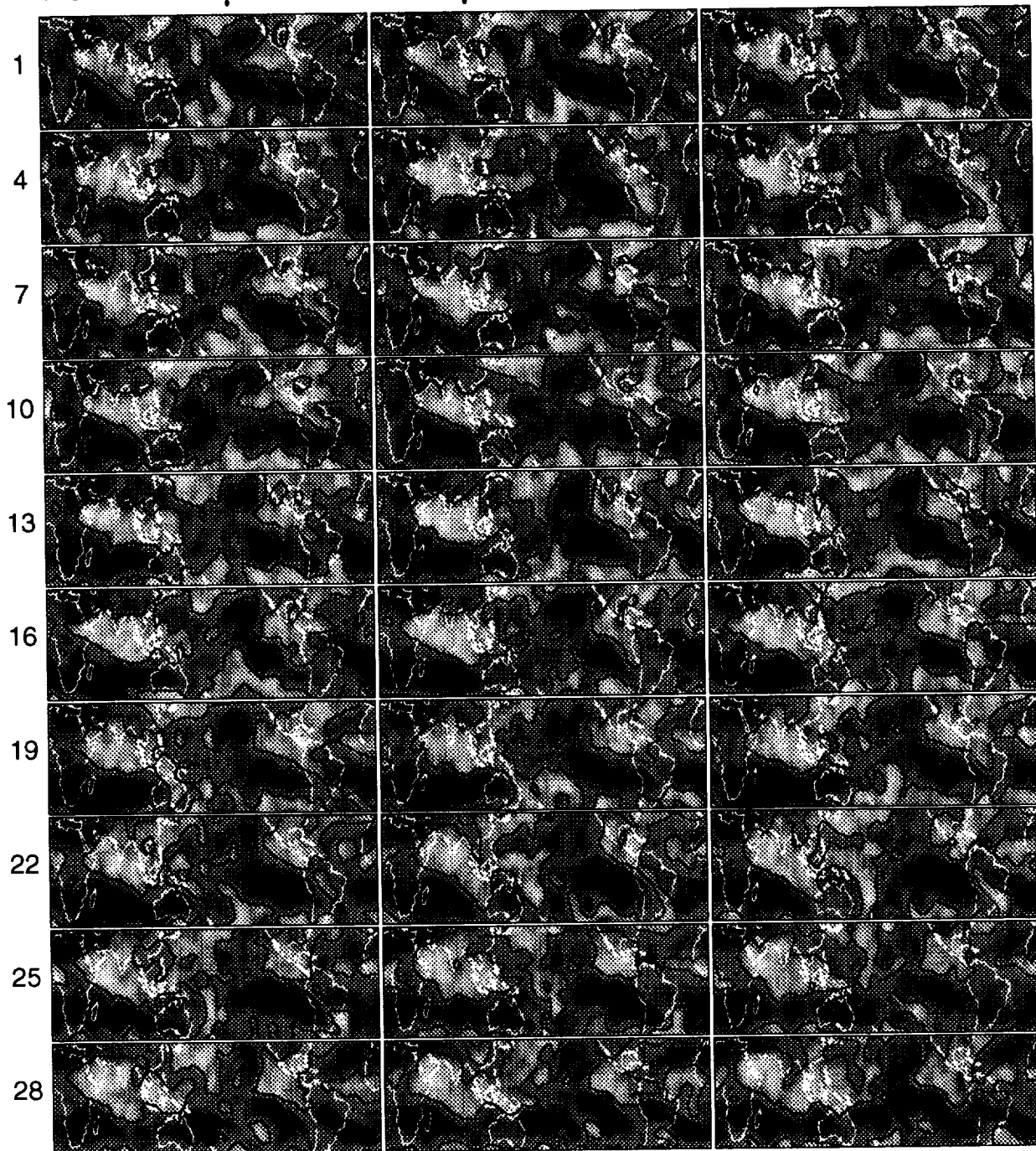
TOVS 6.5 μm Water Vapor Band

May 1981



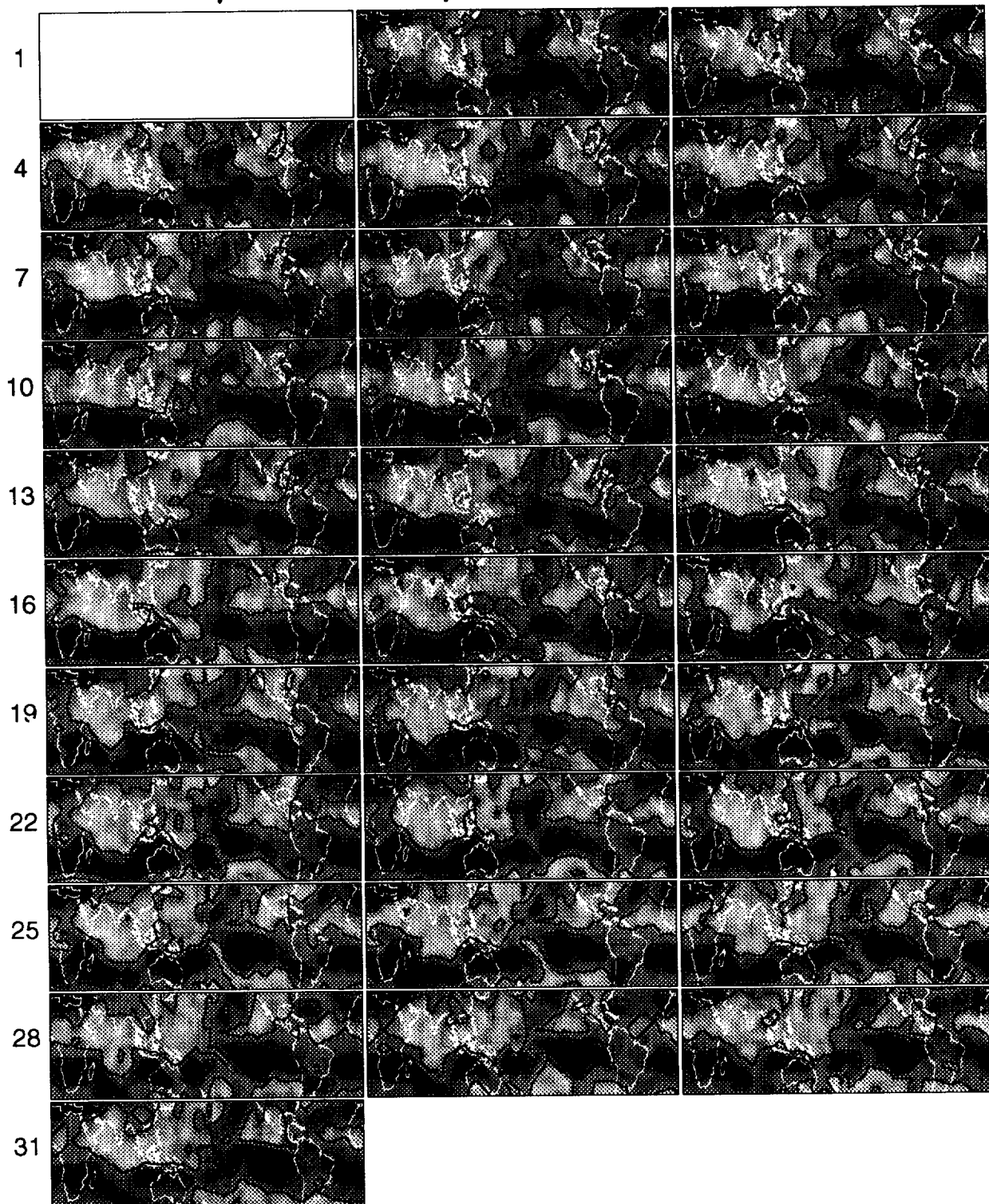
TOVS 6.5 μm Water Vapor Band

June 1981



TOVS 6.5 μm Water Vapor Band

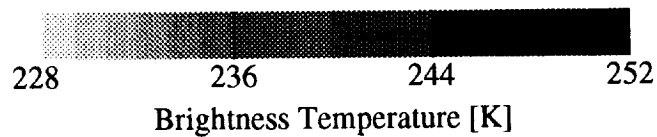
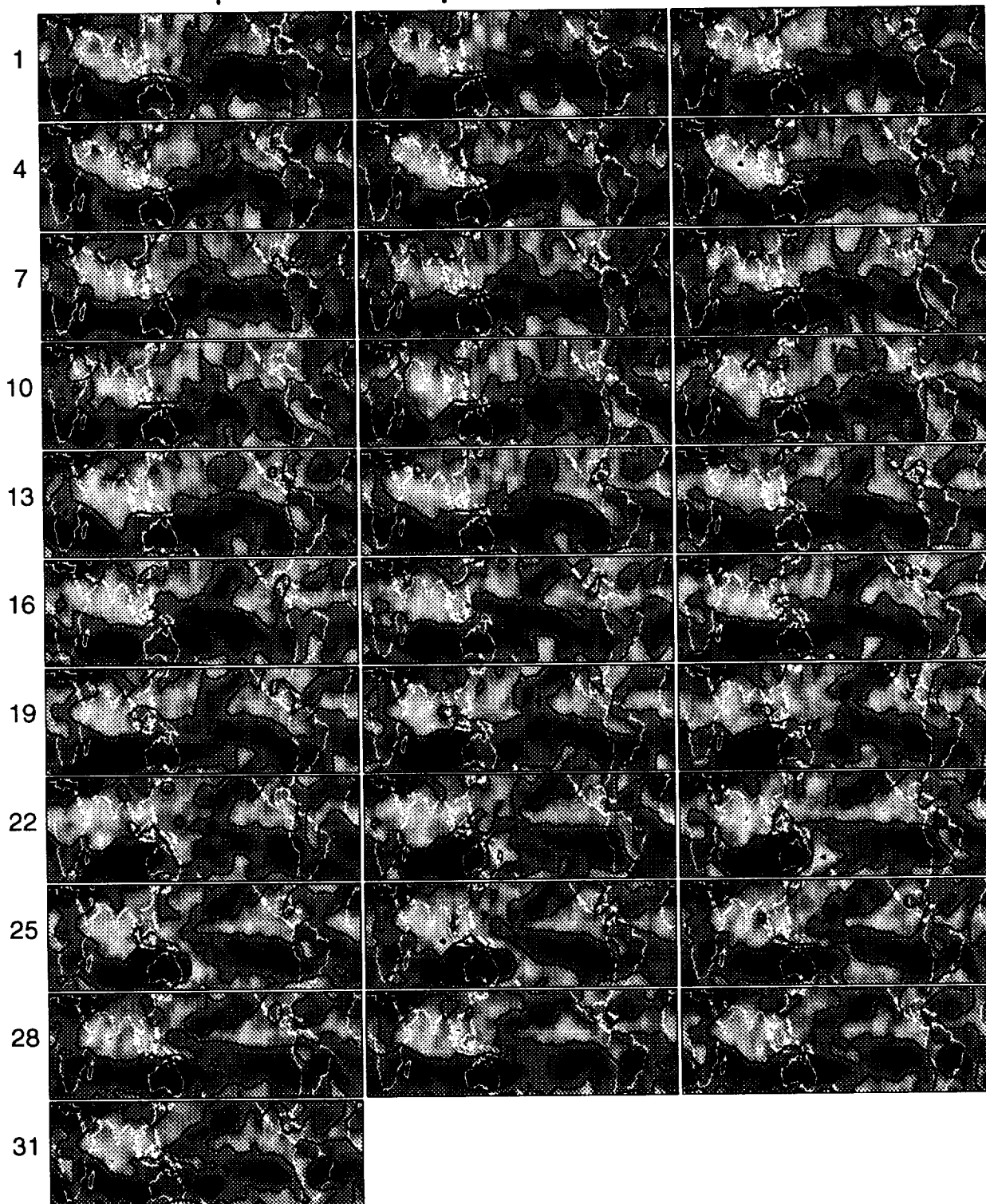
July 1981



228 236 244 252
Brightness Temperature [K]

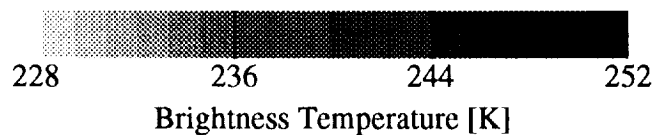
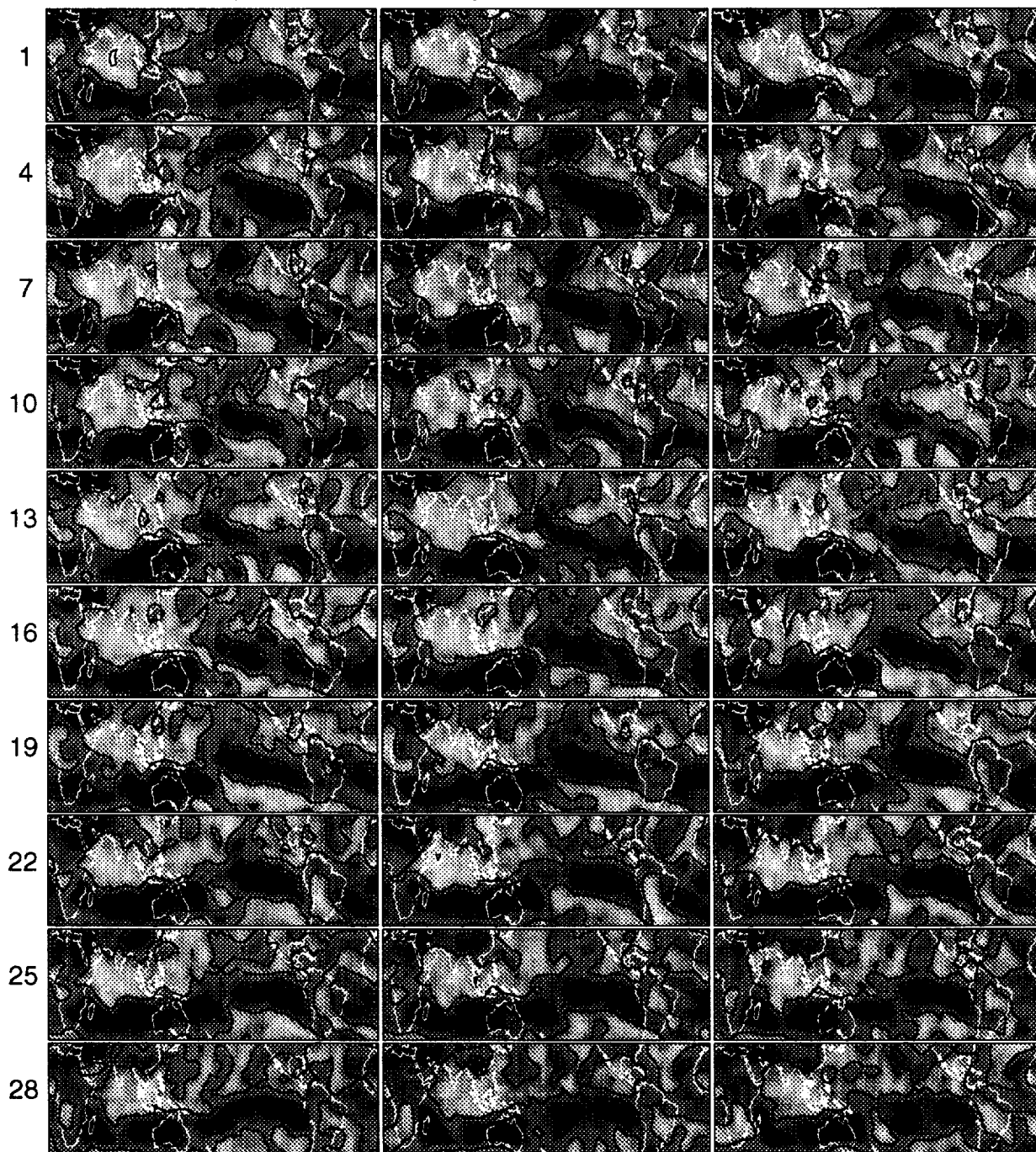
TOVS 6.5 μm Water Vapor Band

August 1981



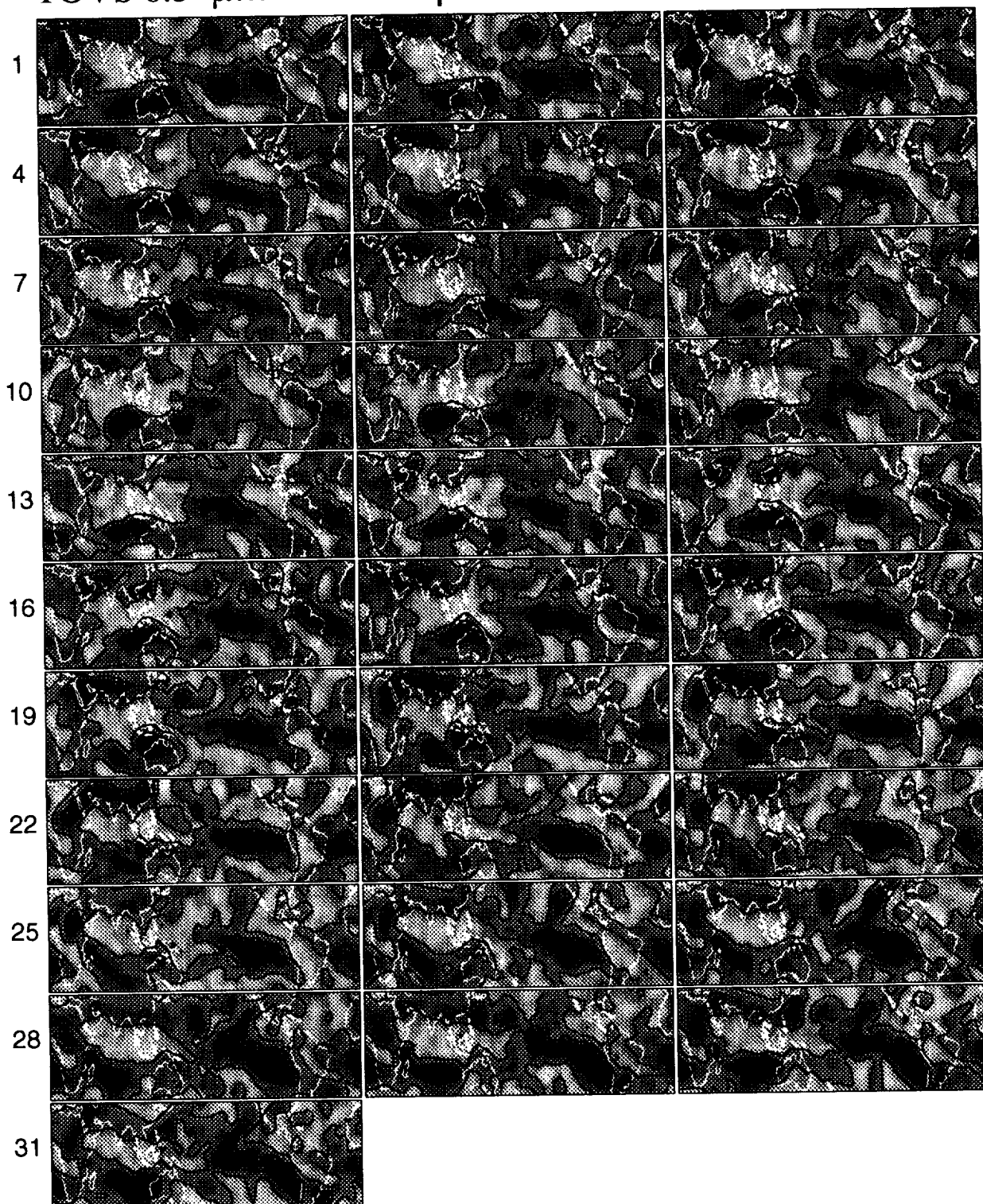
TOVS 6.5 μm Water Vapor Band

September 1981



TOVS 6.5 μm Water Vapor Band

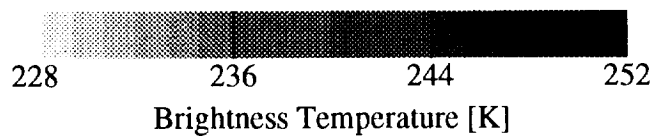
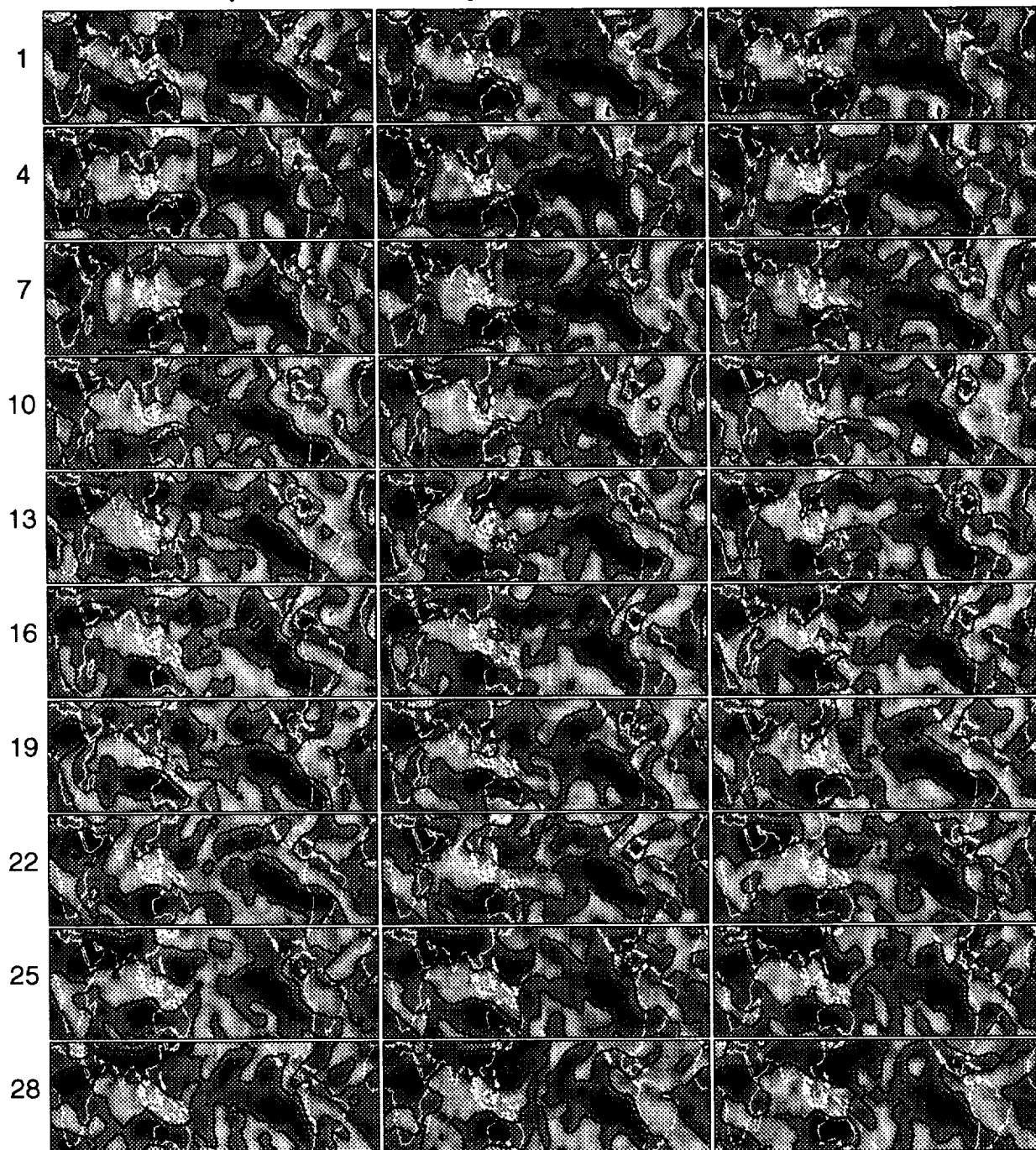
October 1981



Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

November 1981



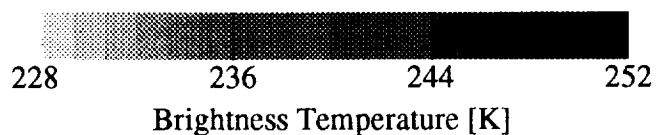
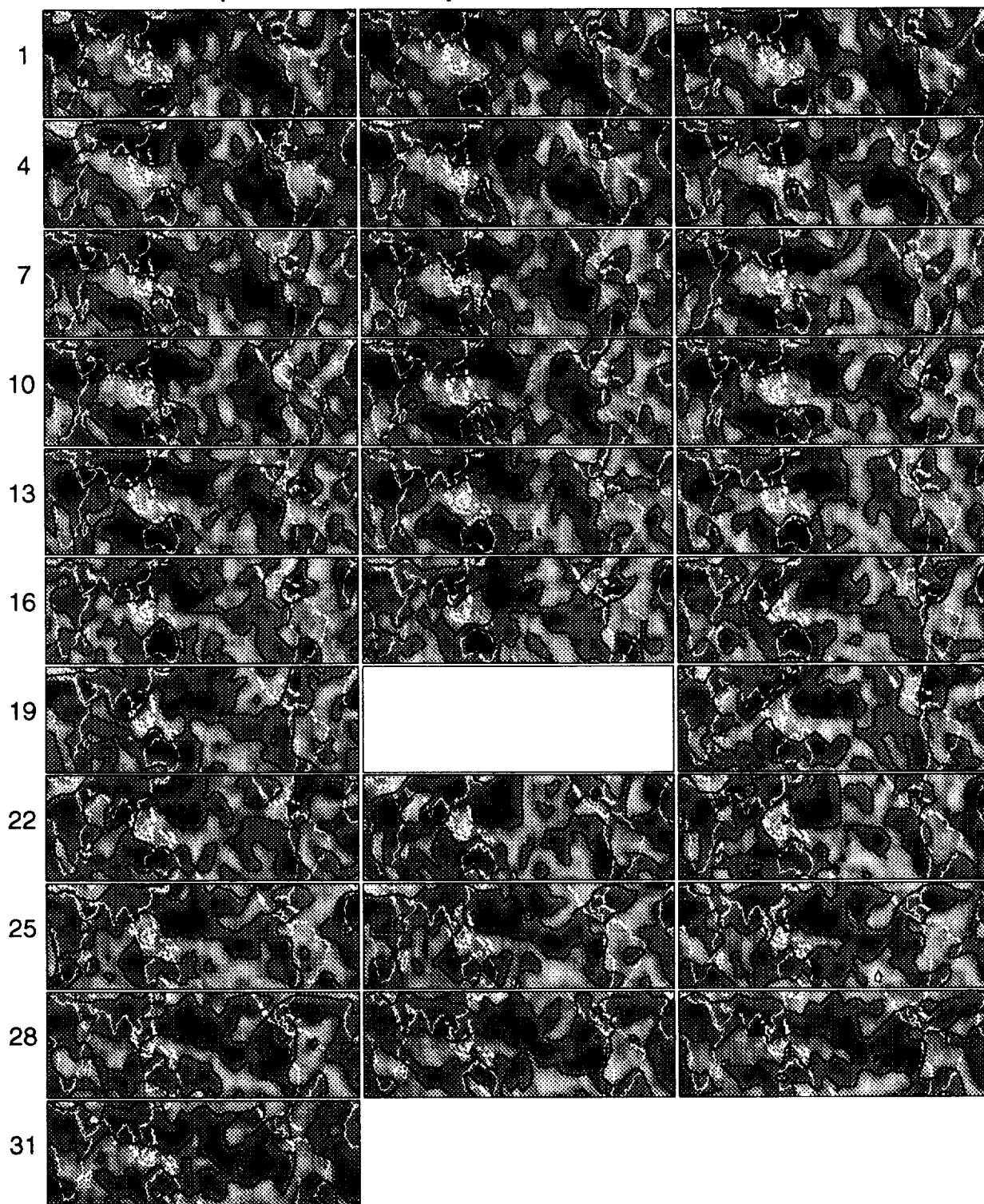
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A-71

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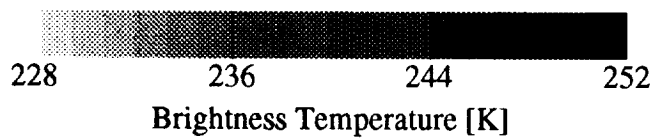
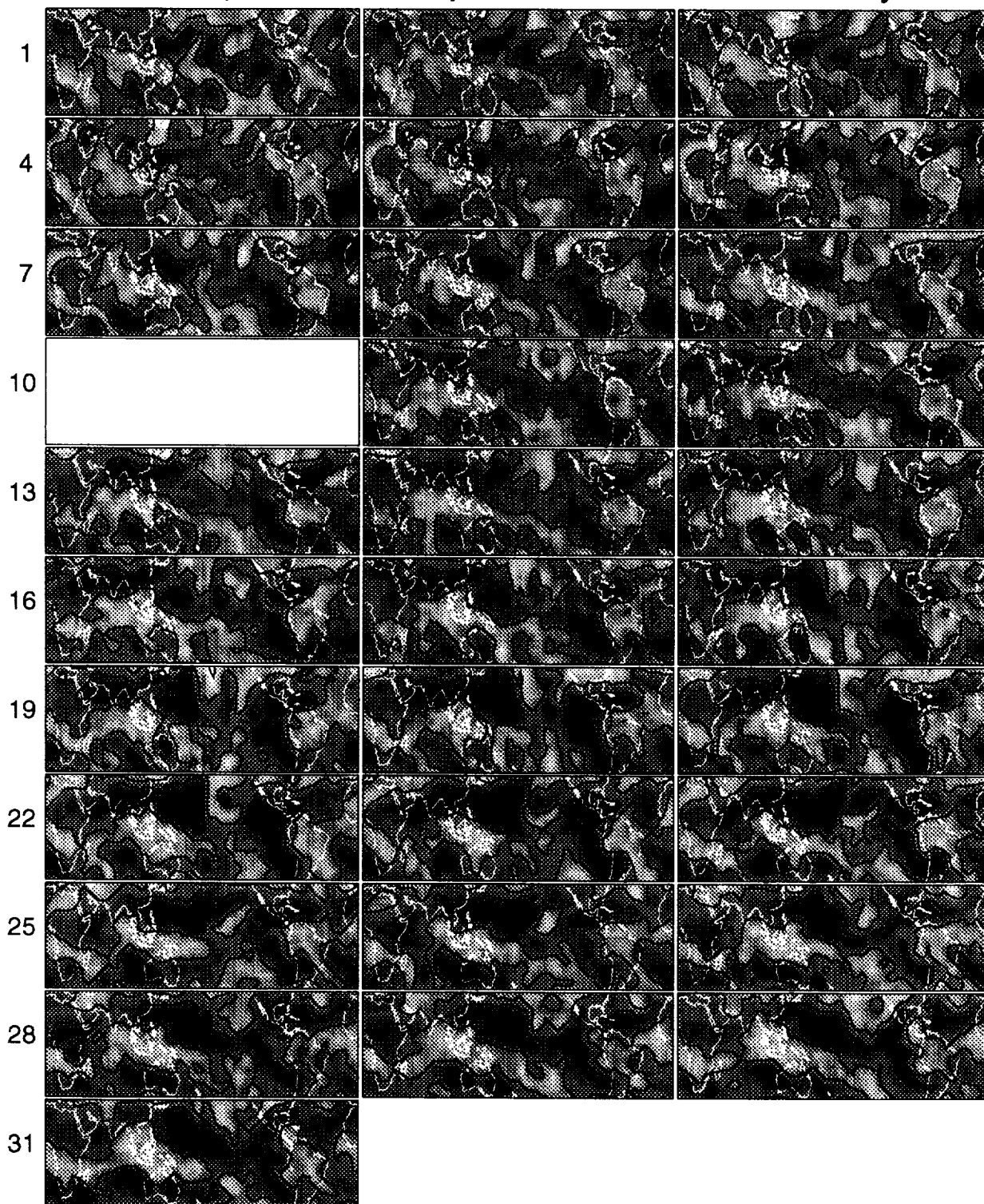
TOVS 6.5 μm Water Vapor Band

December 1981



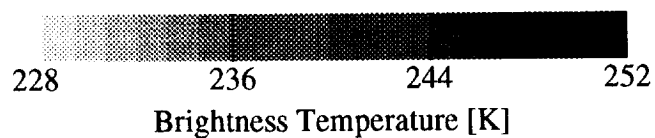
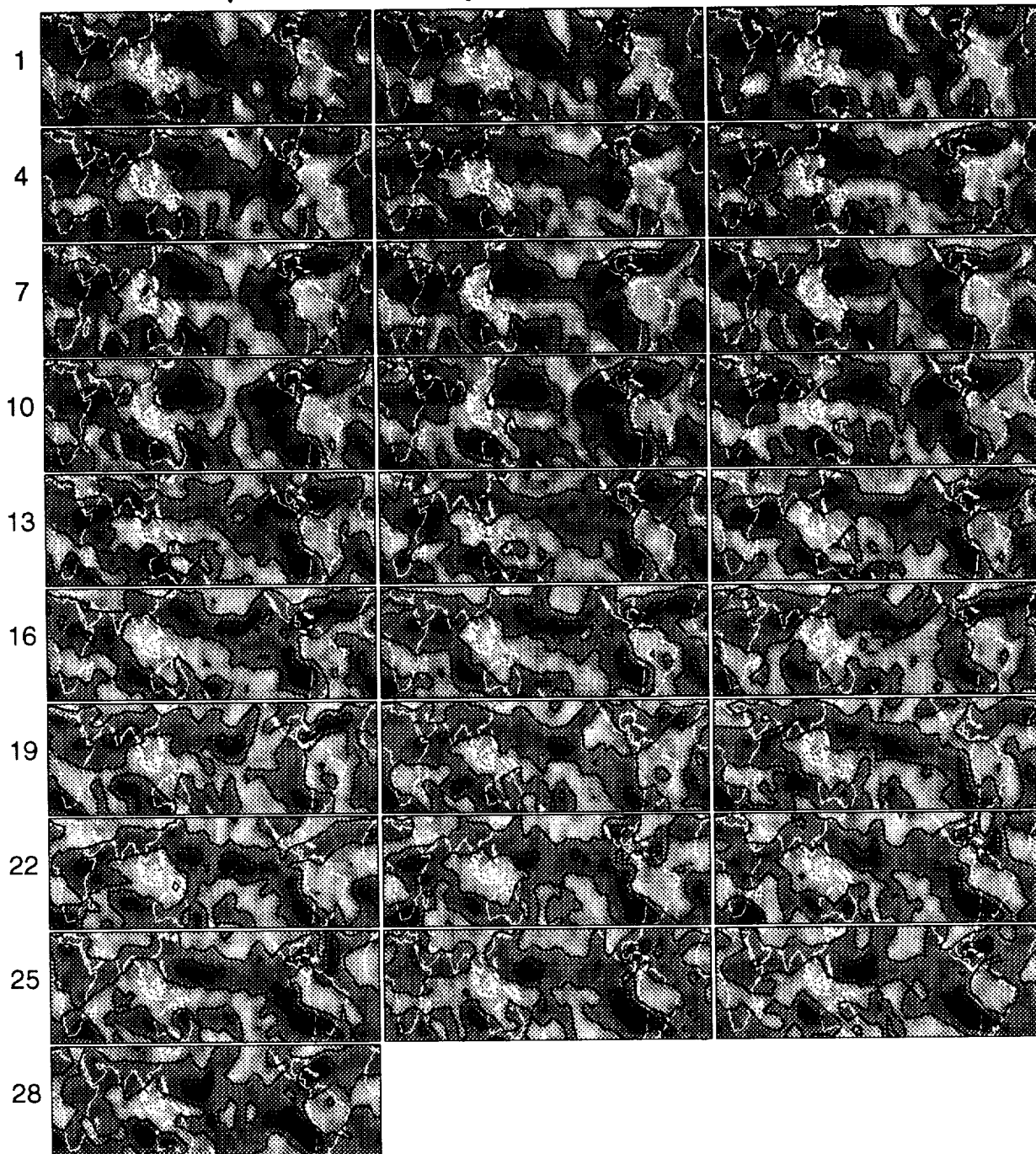
TOVS 6.5 μm Water Vapor Band

January 1982



TOVS 6.5 μm Water Vapor Band

February 1982



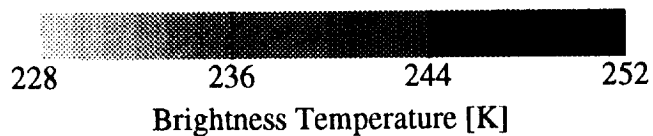
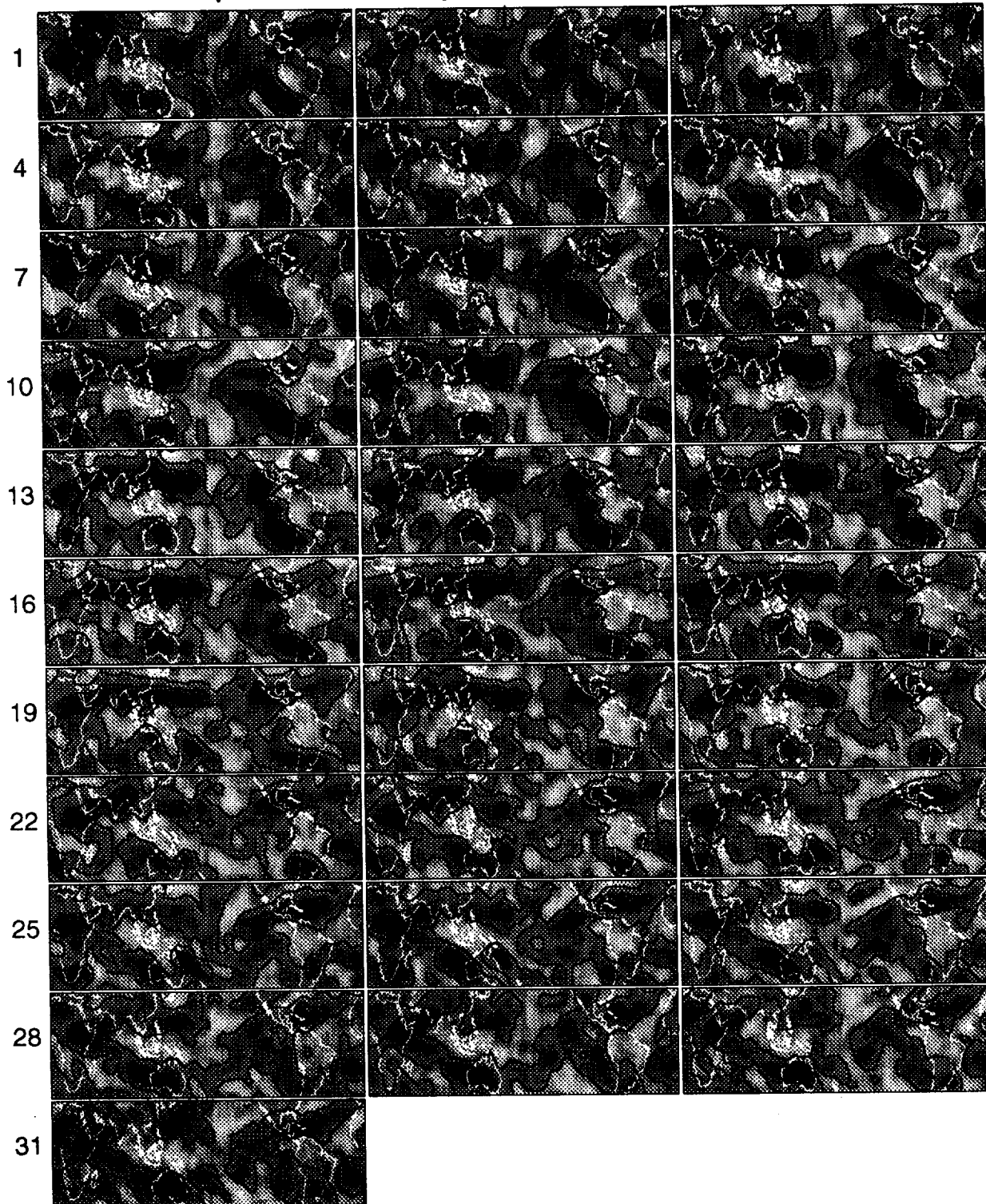
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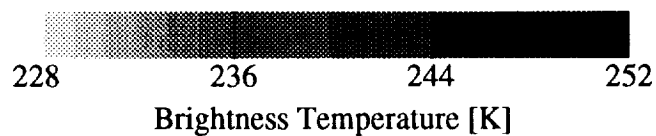
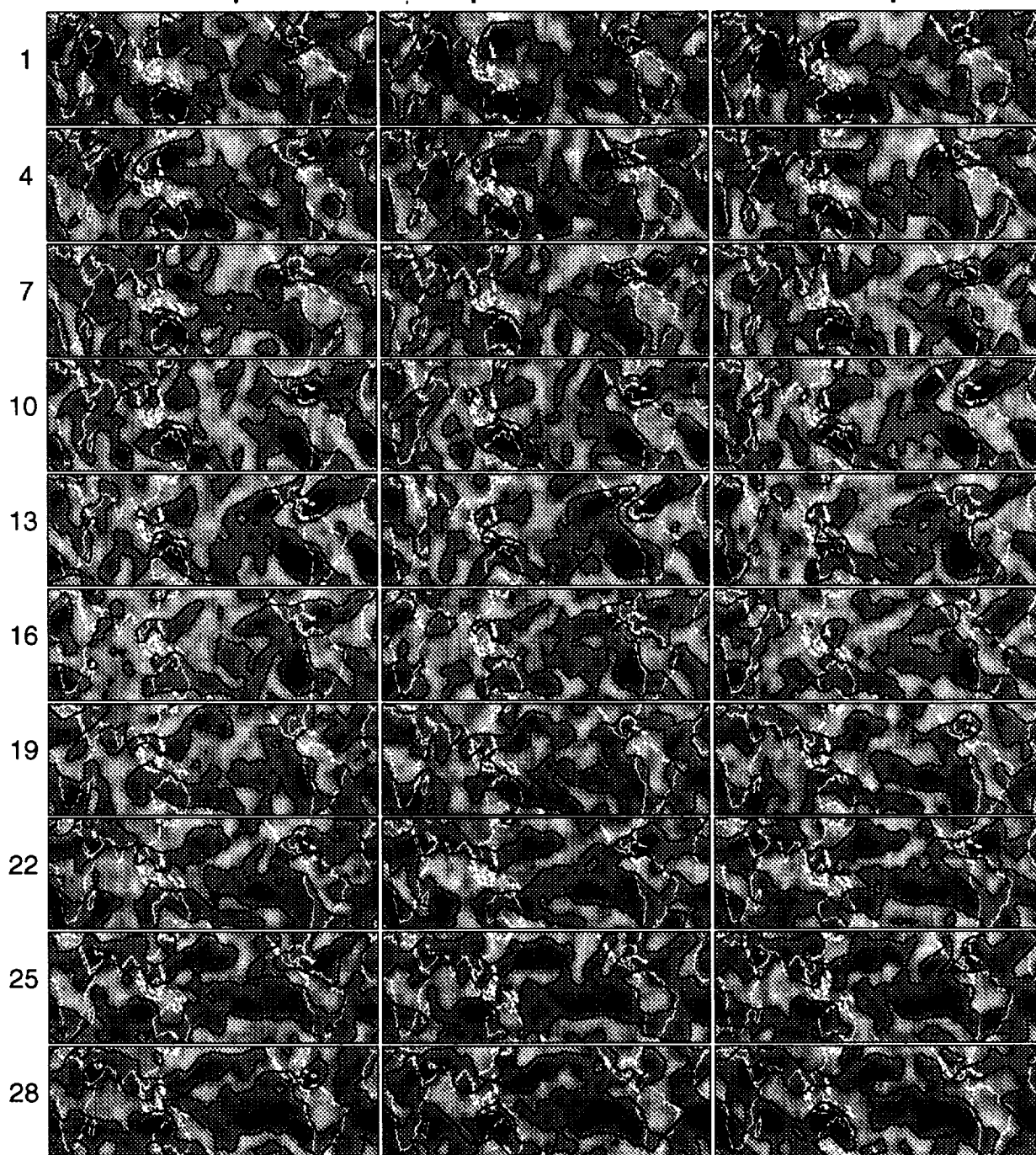
TOVS 6.5 μm Water Vapor Band

March 1982



TOVS 6.5 μm Water Vapor Band

April 1982



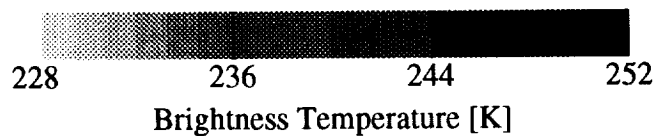
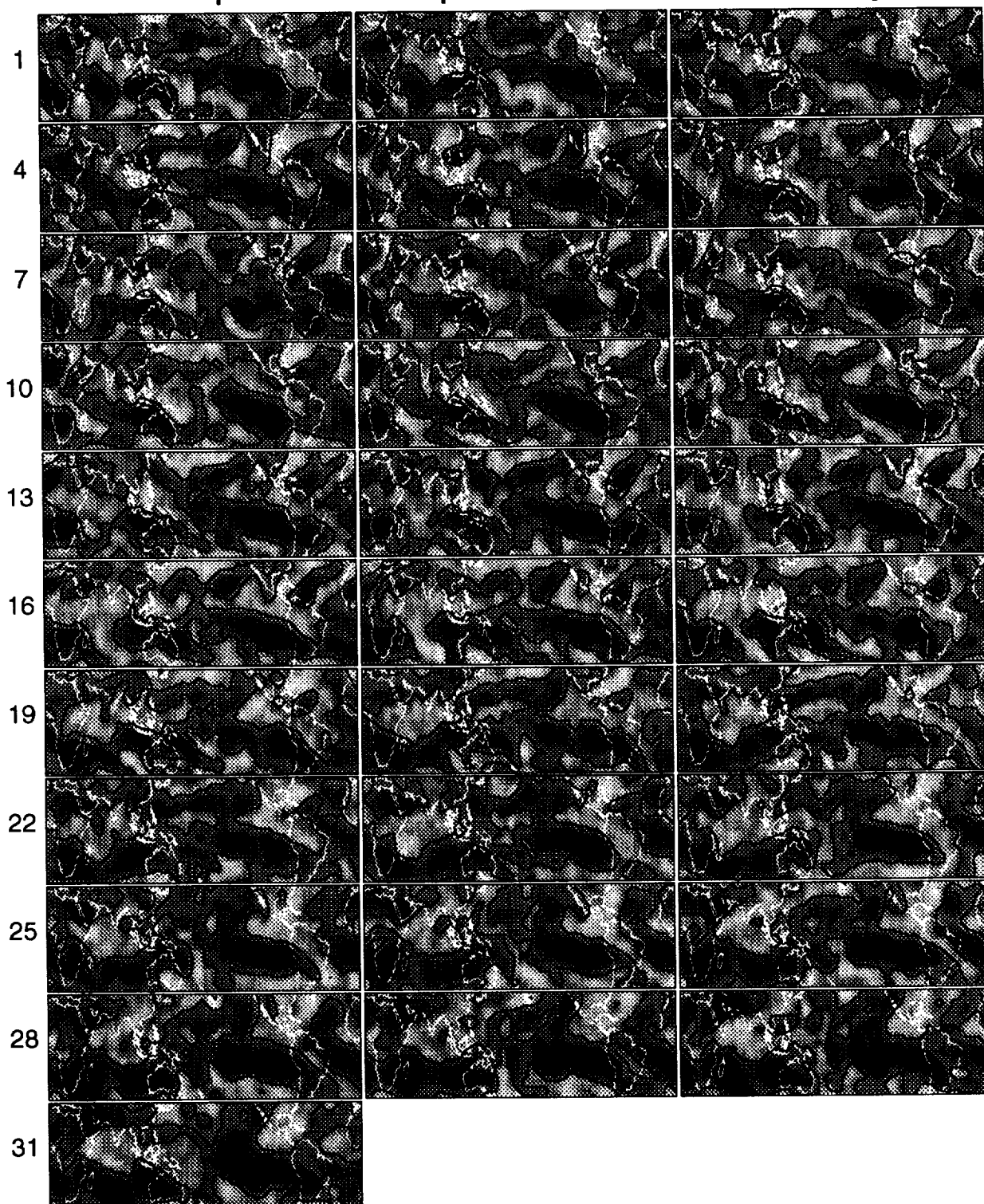
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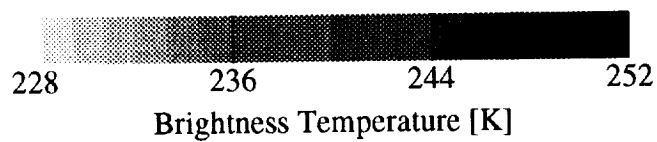
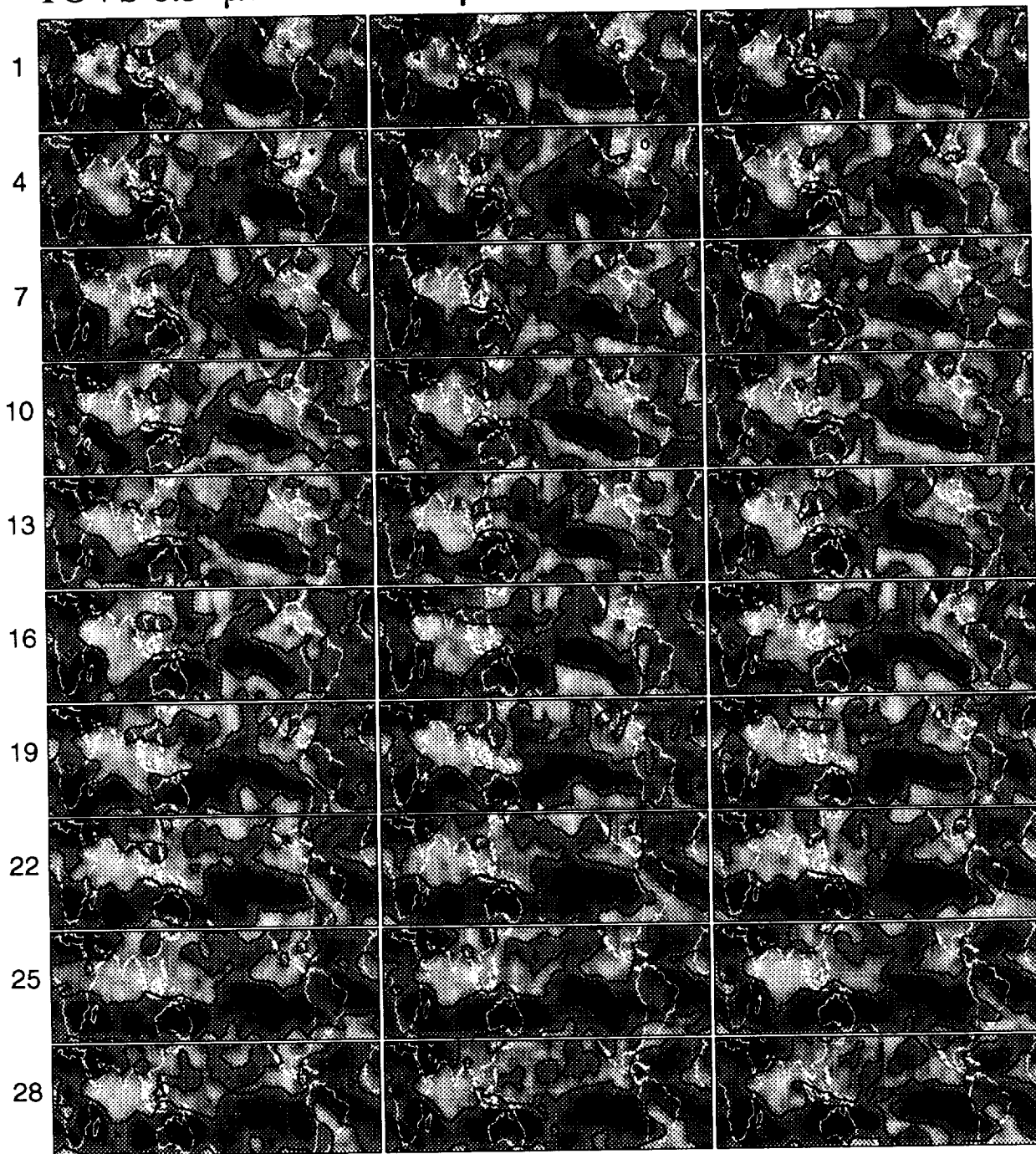
TOVS 6.5 μm Water Vapor Band

May 1982



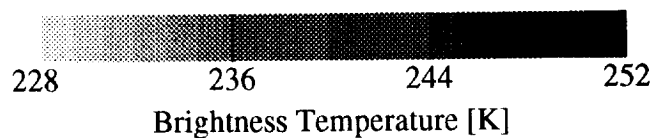
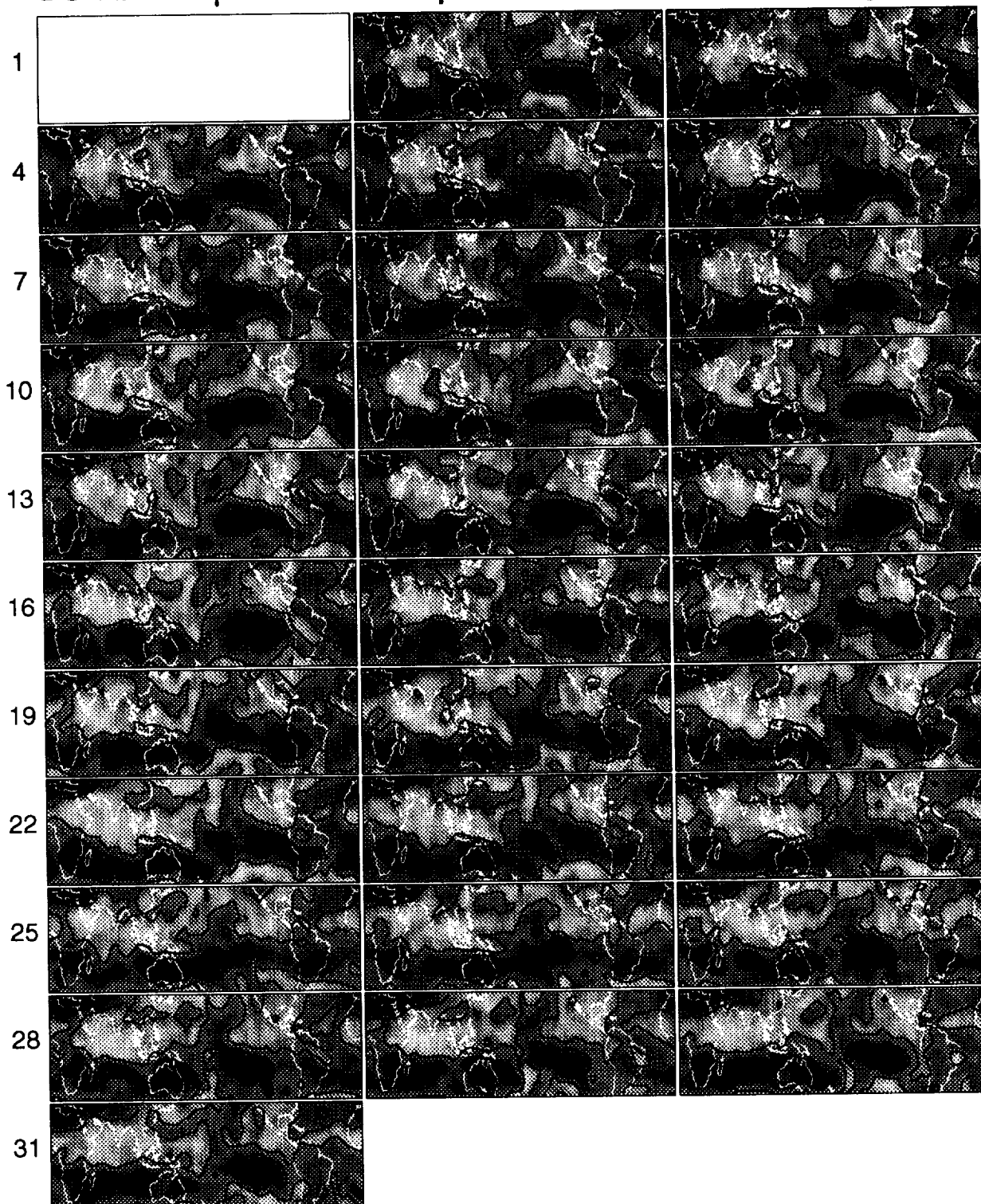
TOVS 6.5 μm Water Vapor Band

June 1982

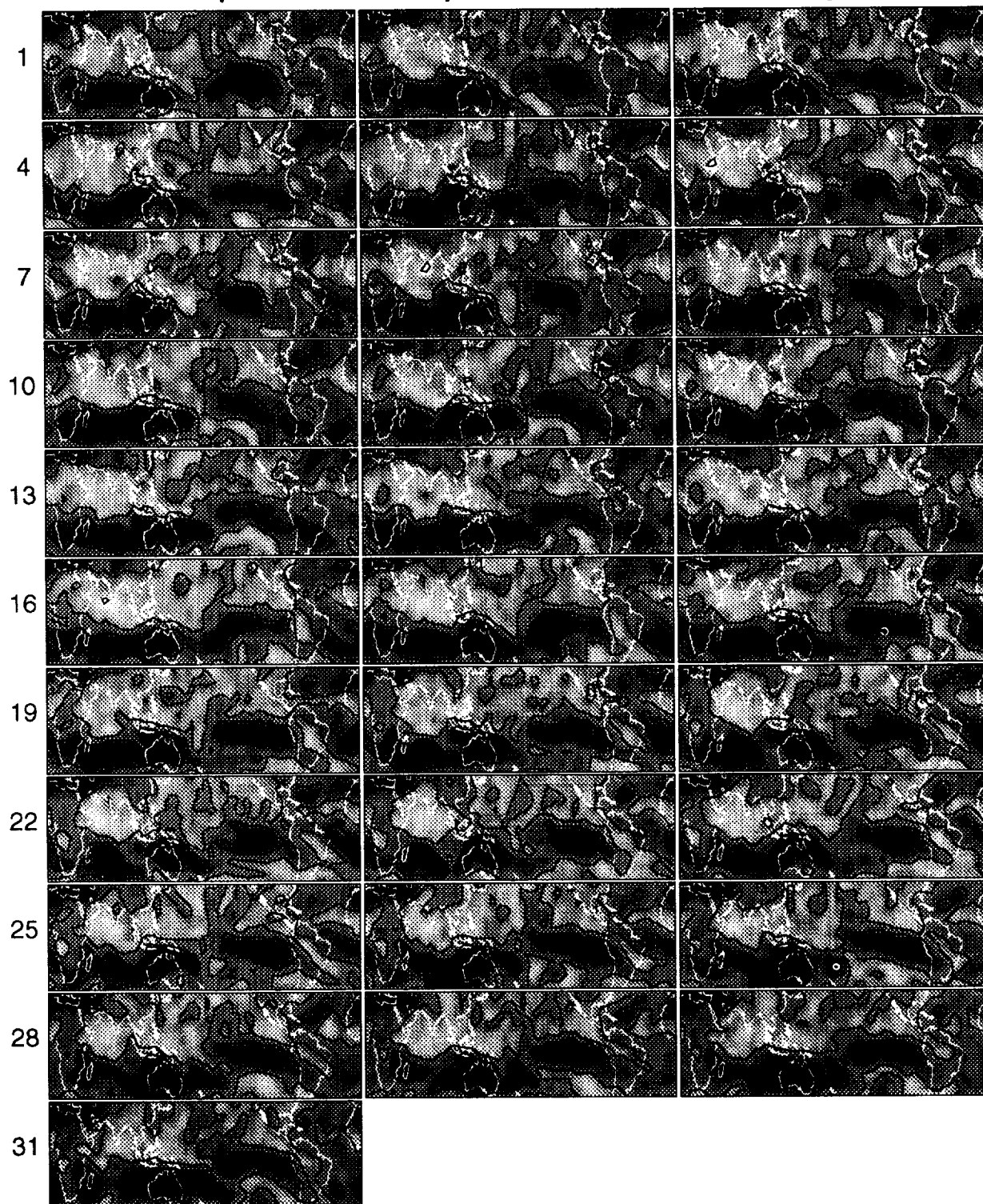


TOVS 6.5 μm Water Vapor Band

July 1982



August 1982



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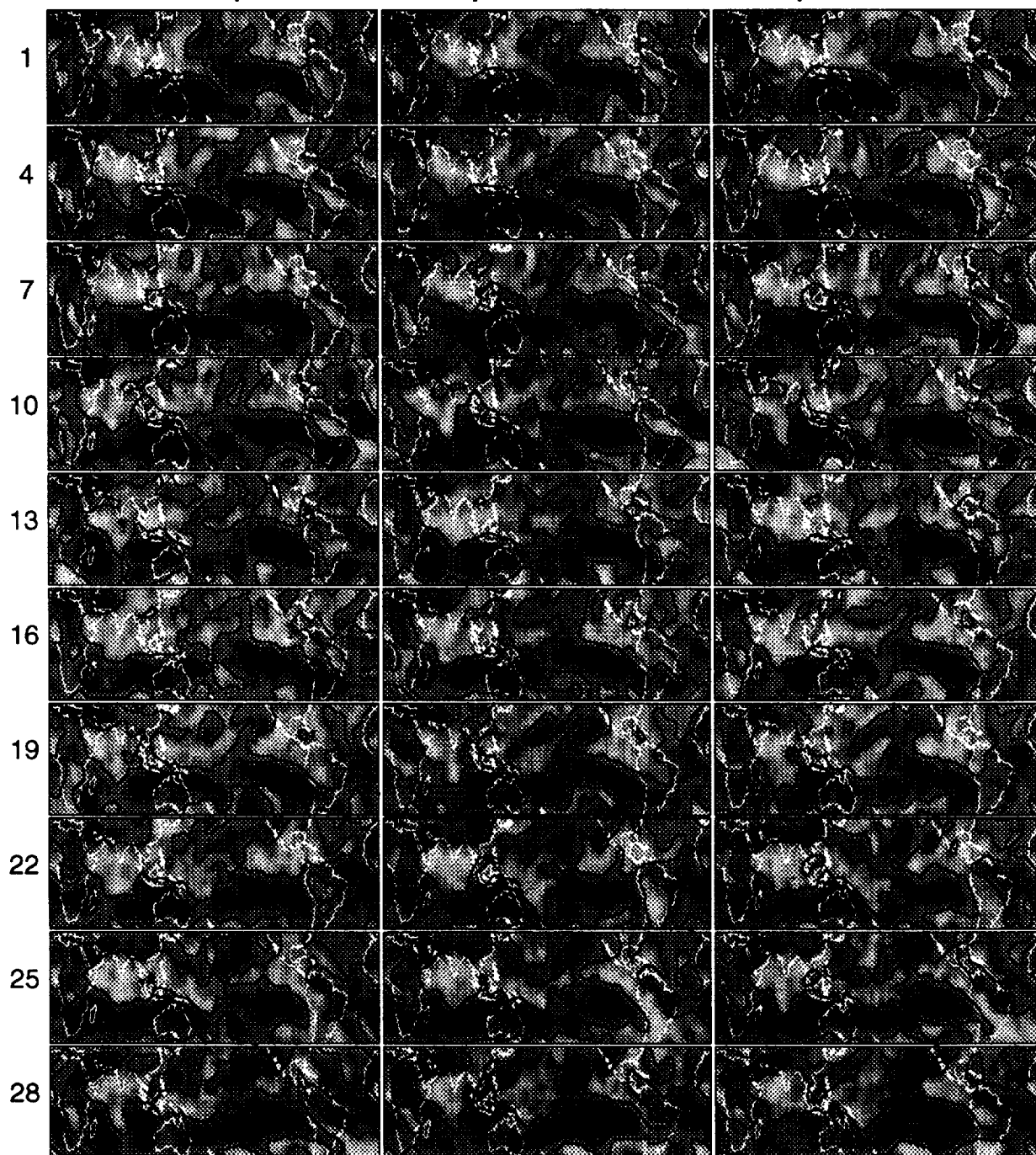
236

244

252

Brightness Temperature [K]

September 1982



228

236

244

252

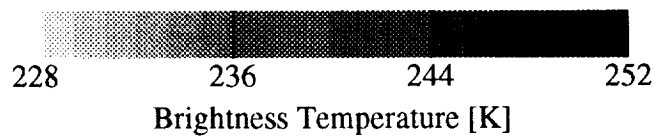
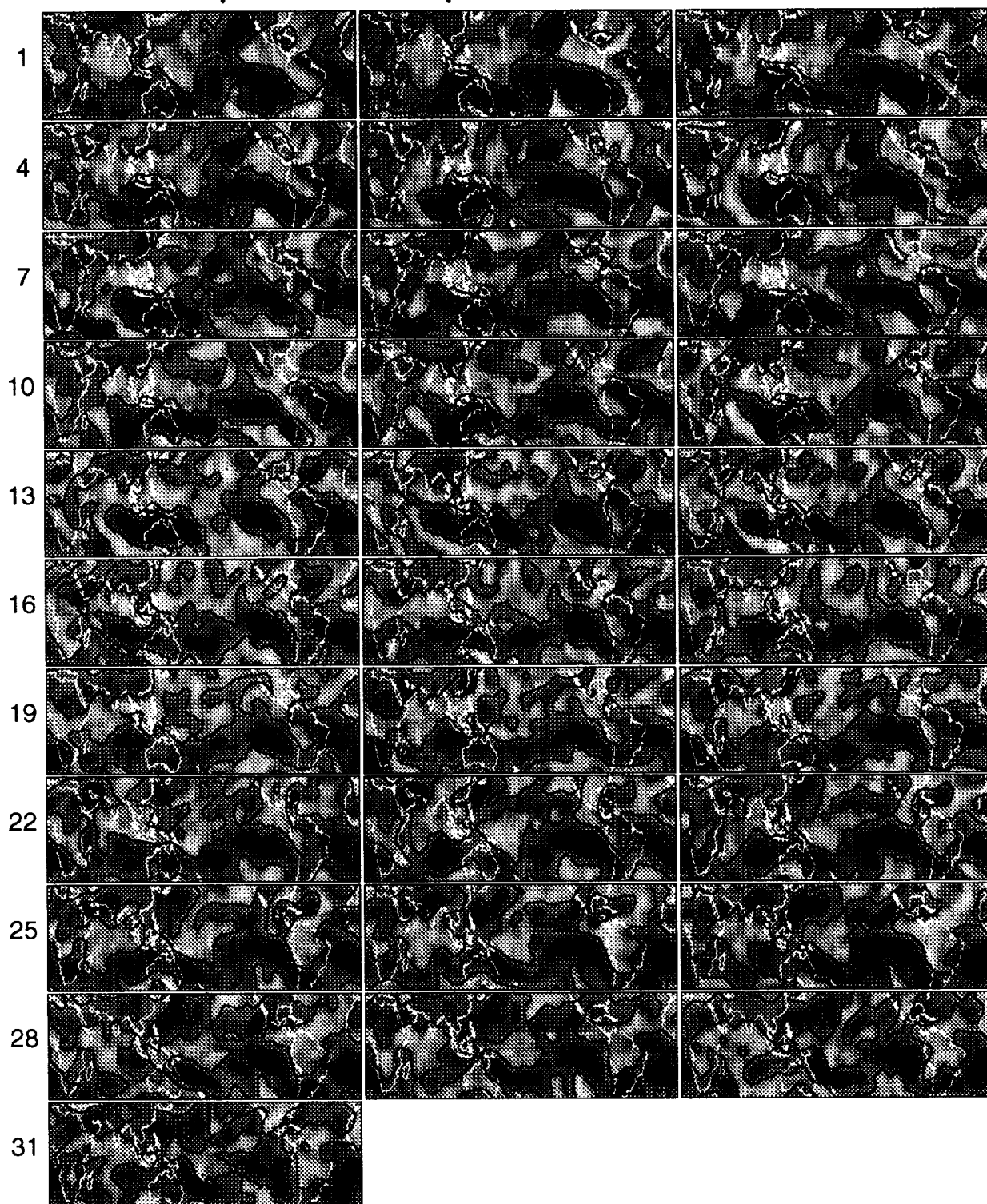
Brightness Temperature [K]

A-90 INTENTIONALLY BLANK

A-91

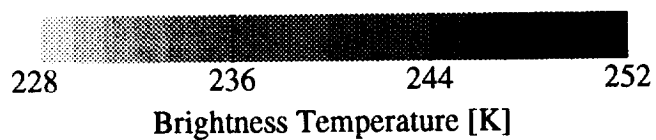
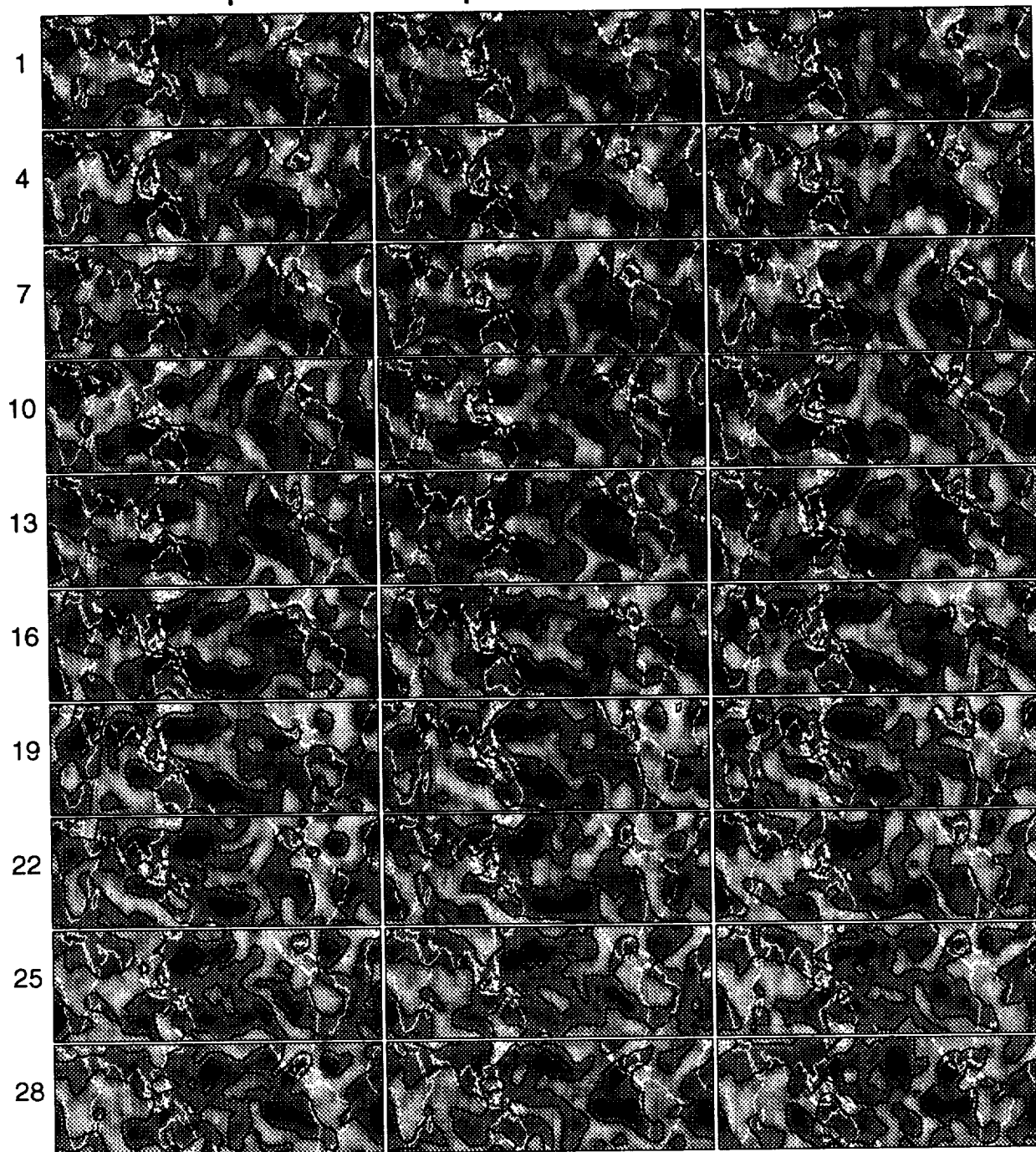
TOVS 6.5 μm Water Vapor Band

October 1982



TOVS 6.5 μm Water Vapor Band

November 1982

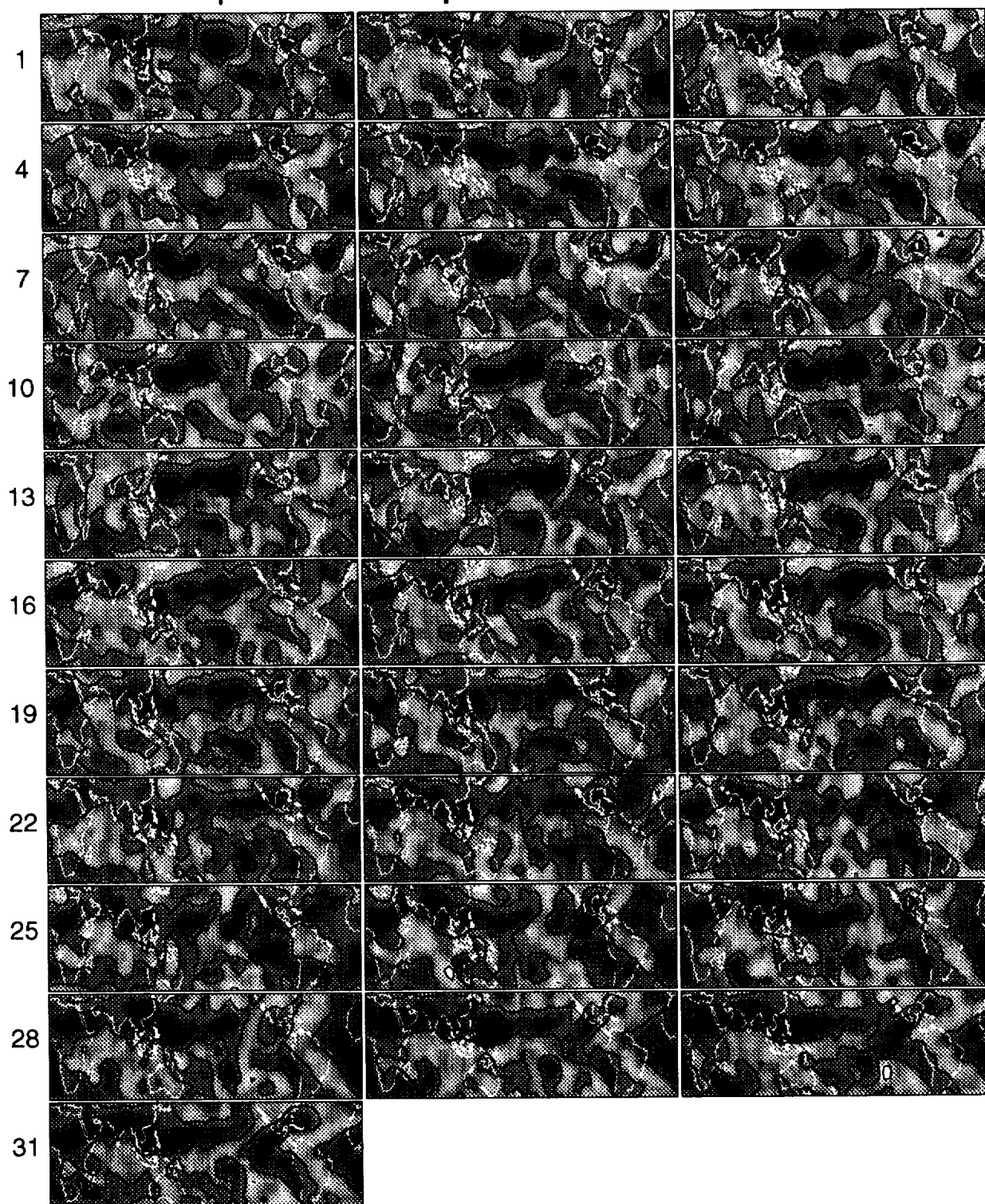


A-95

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NOV 1982

December 1982



228

236

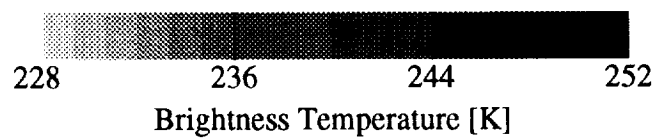
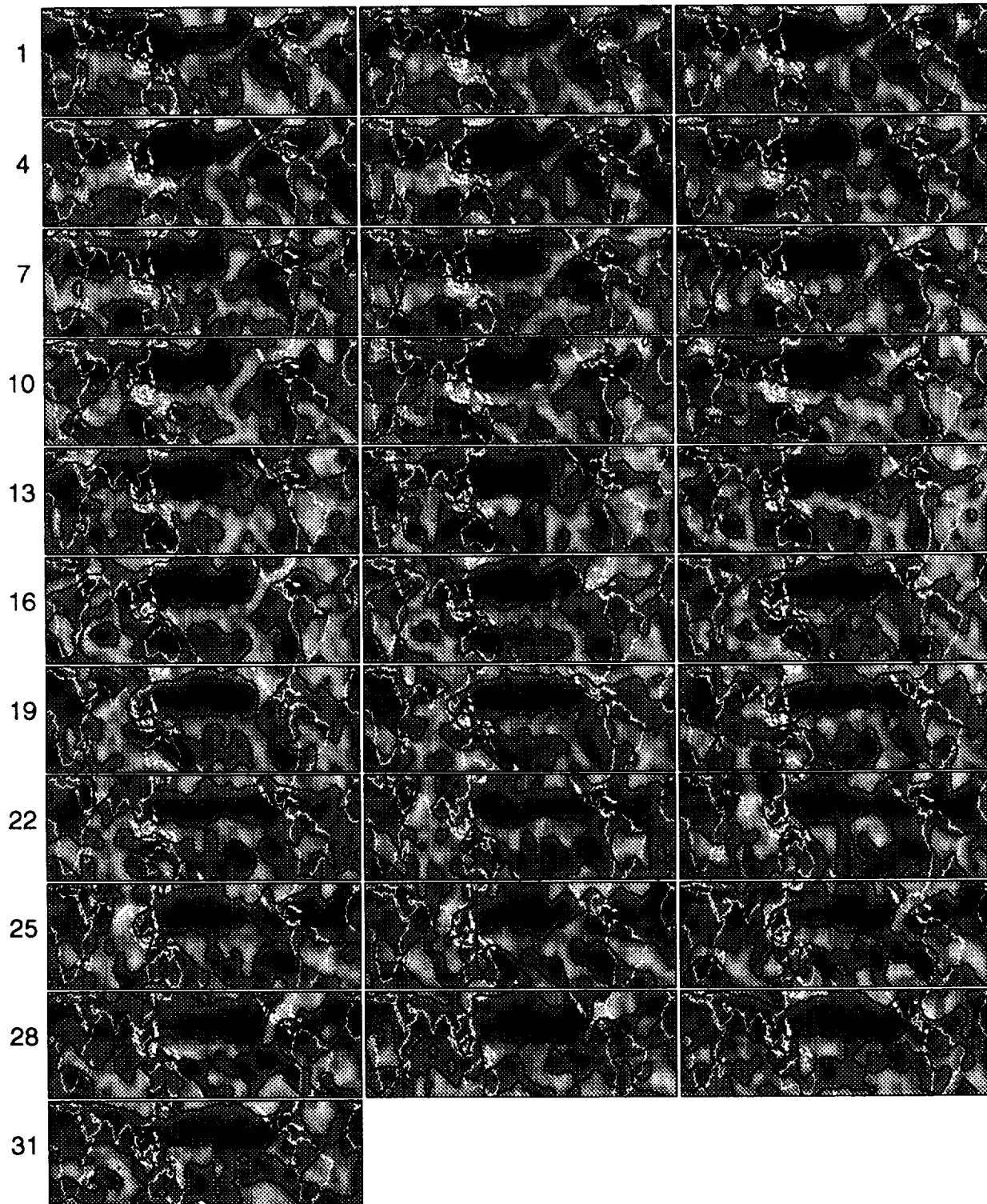
244

252

Brightness Temperature [K]

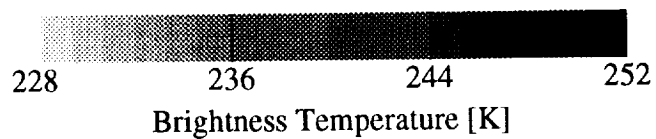
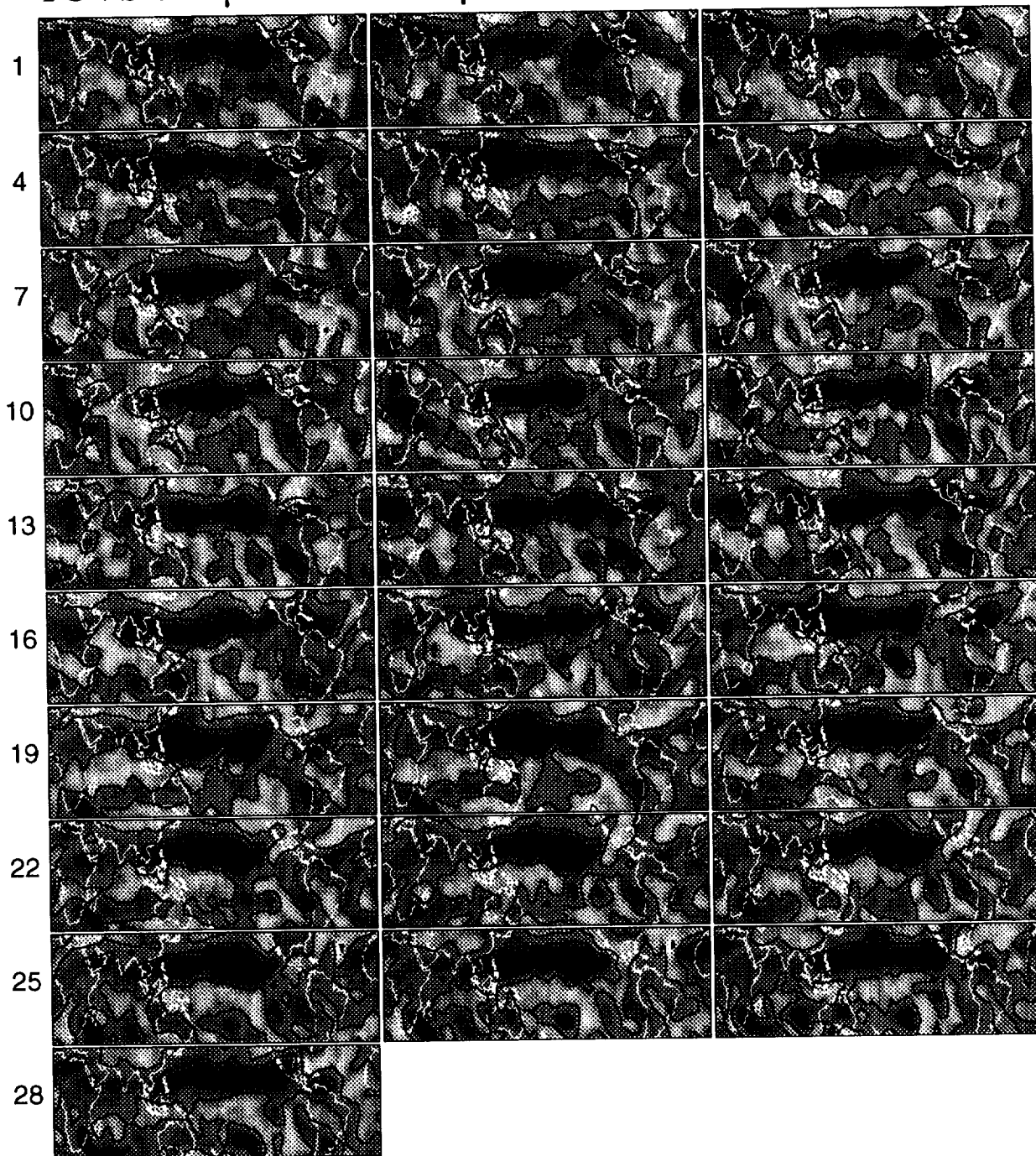
TOVS 6.5 μm Water Vapor Band

January 1983



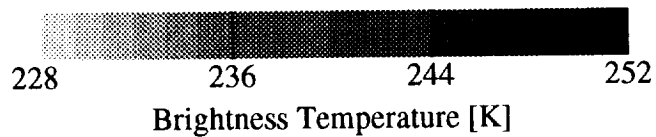
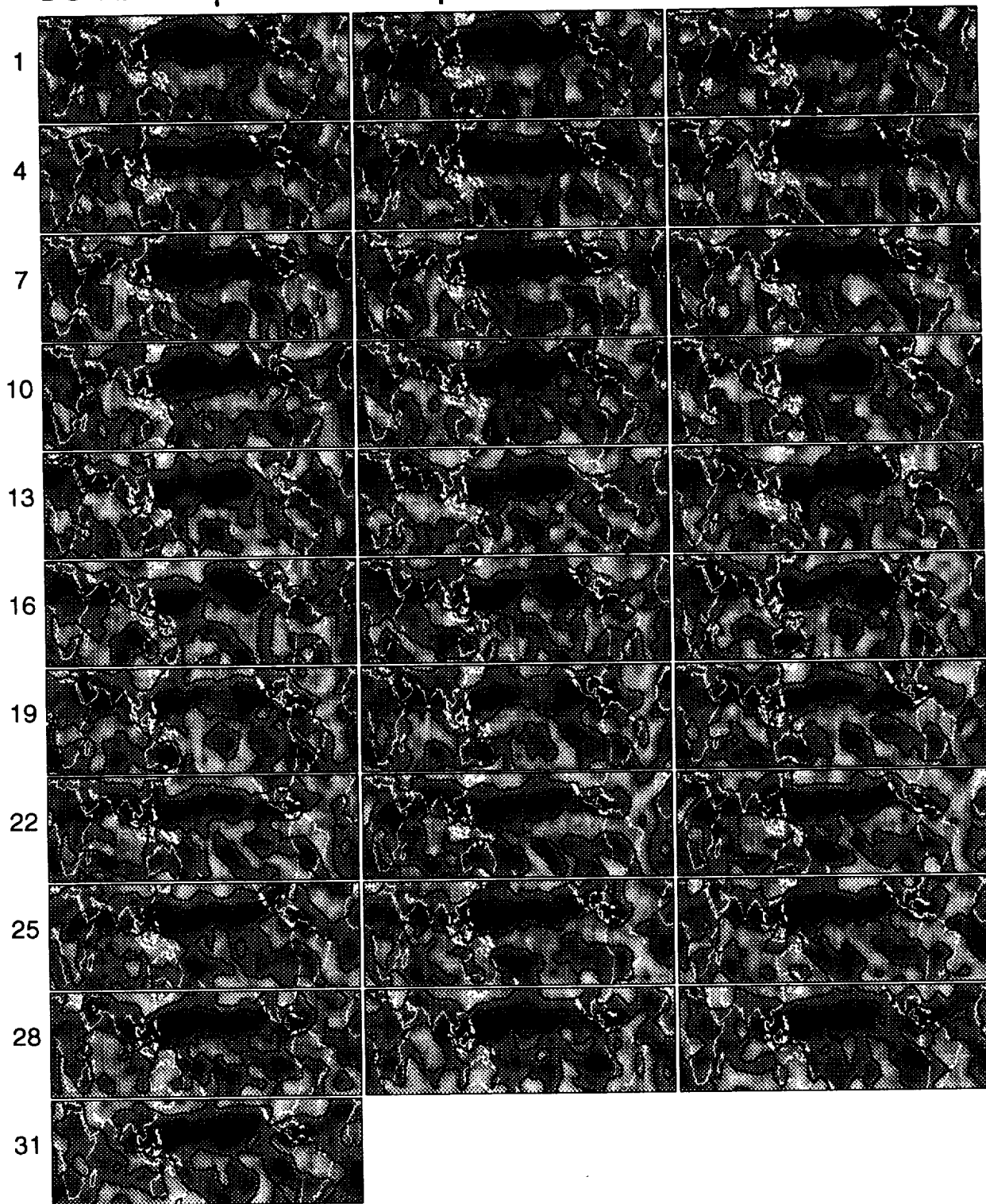
TOVS 6.5 μm Water Vapor Band

February 1983



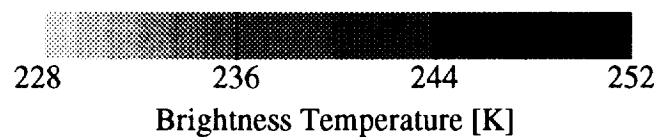
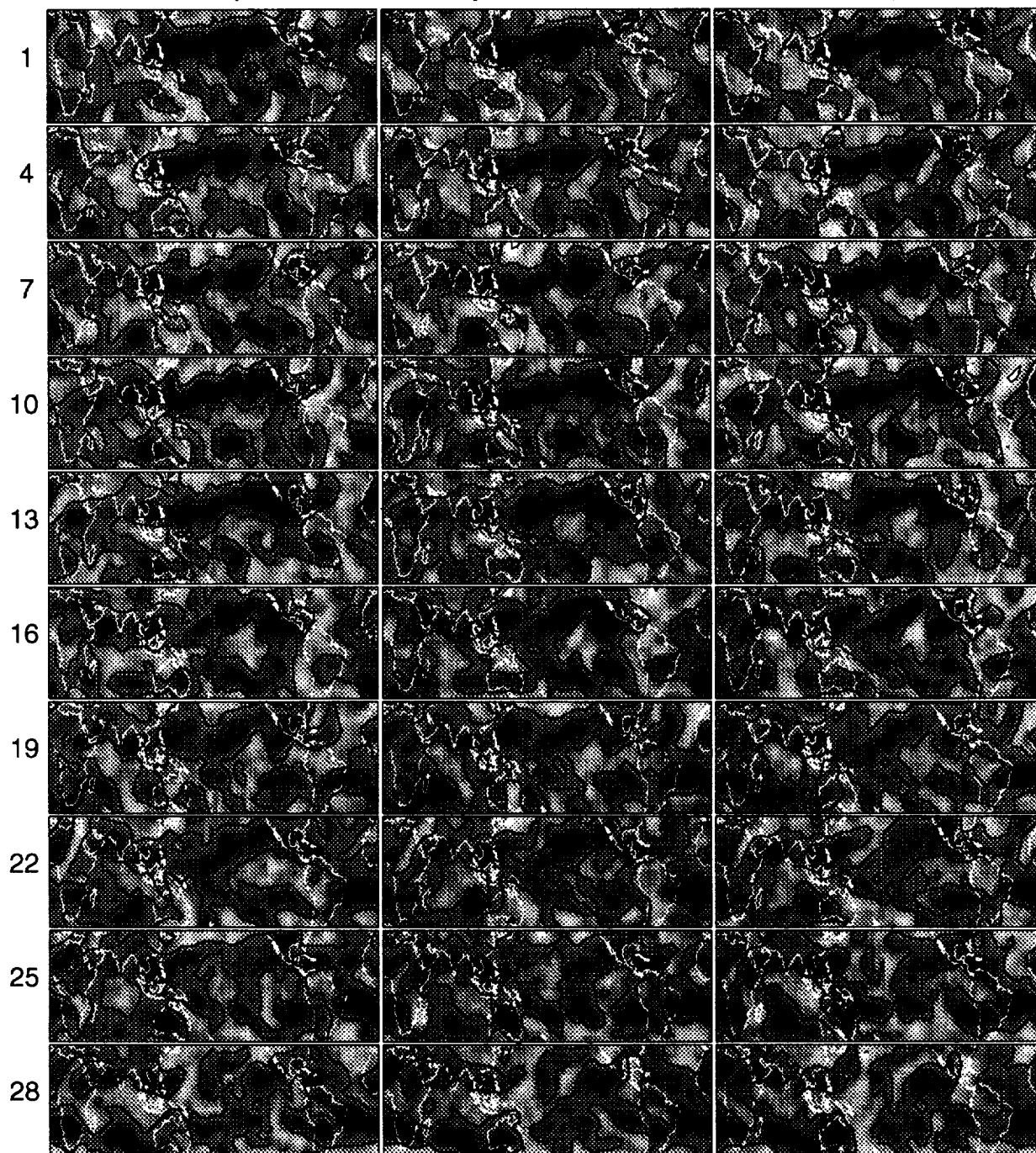
TOVS 6.5 μm Water Vapor Band

March 1983



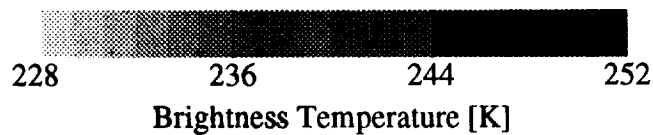
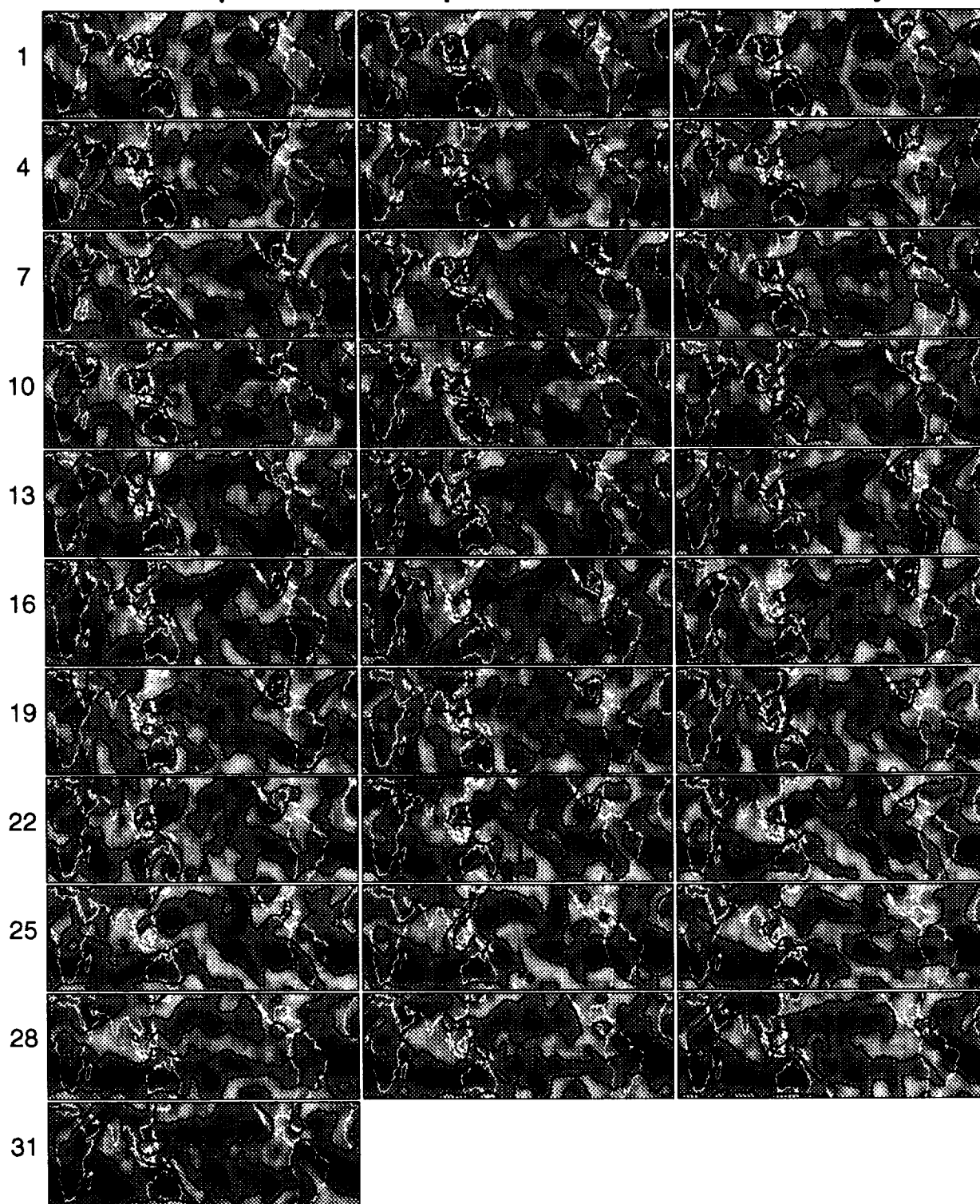
TOVS 6.5 μm Water Vapor Band

April 1983

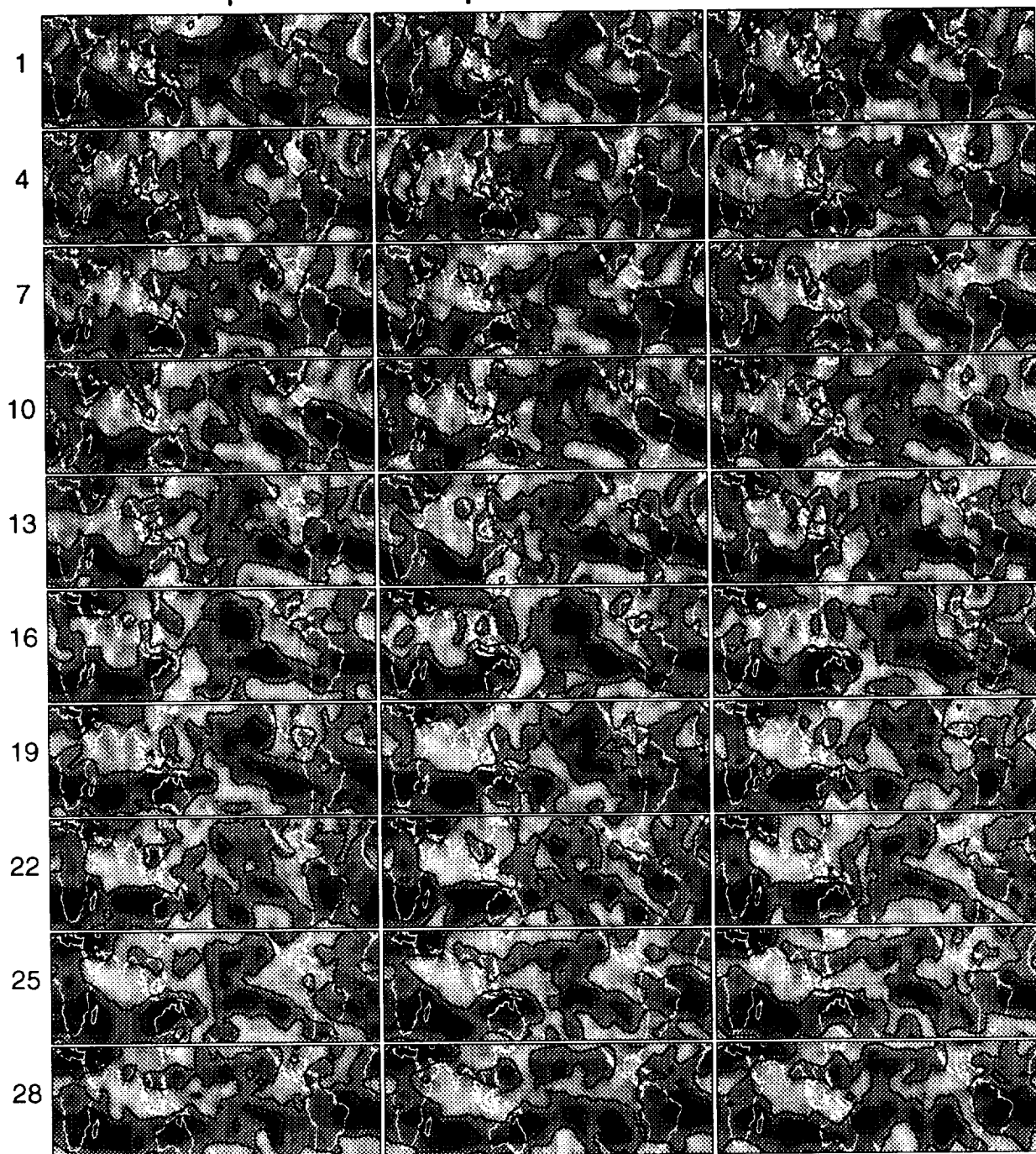


TOVS 6.5 μ m Water Vapor Band

May 1983



June 1983



228

236

244

252

Brightness Temperature [K]

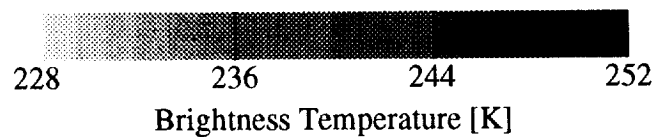
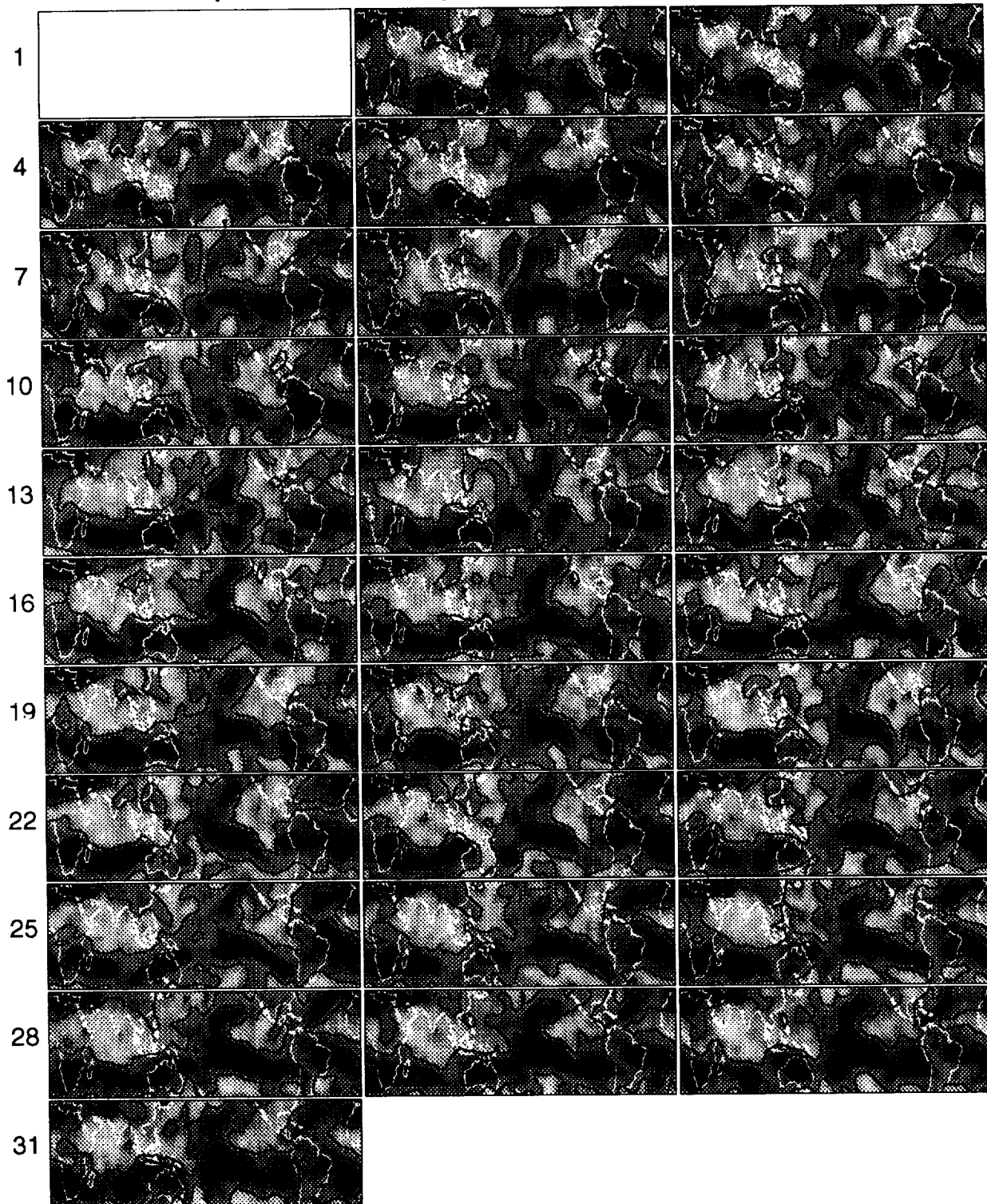
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A-108 INTENTIONALLY BLANK

PRECEDENT: 1984-1985

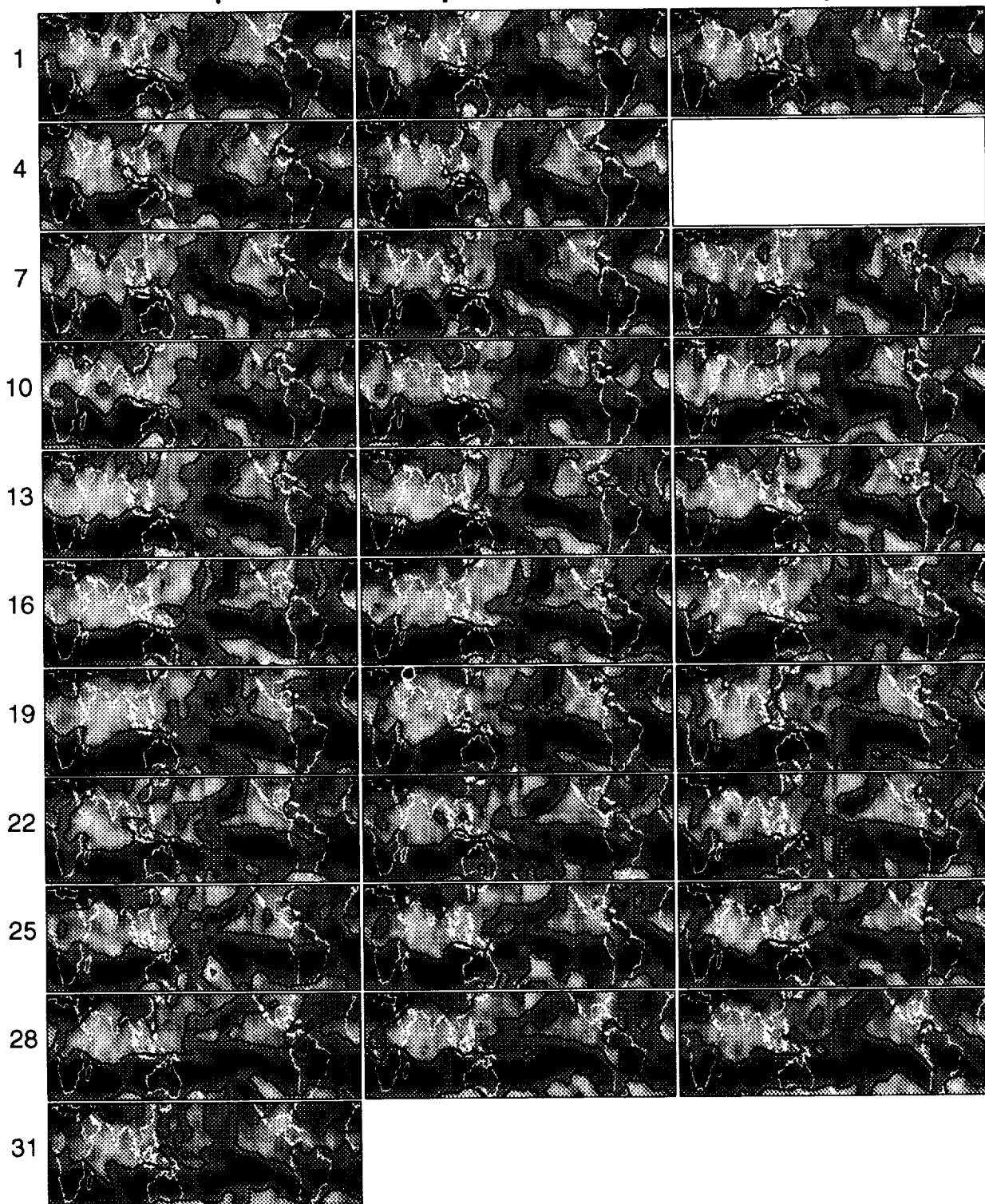
TOVS 6.5 μm Water Vapor Band

July 1983



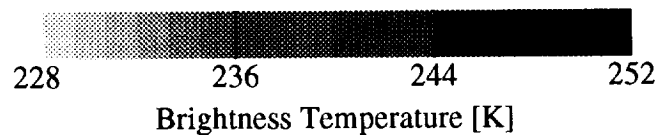
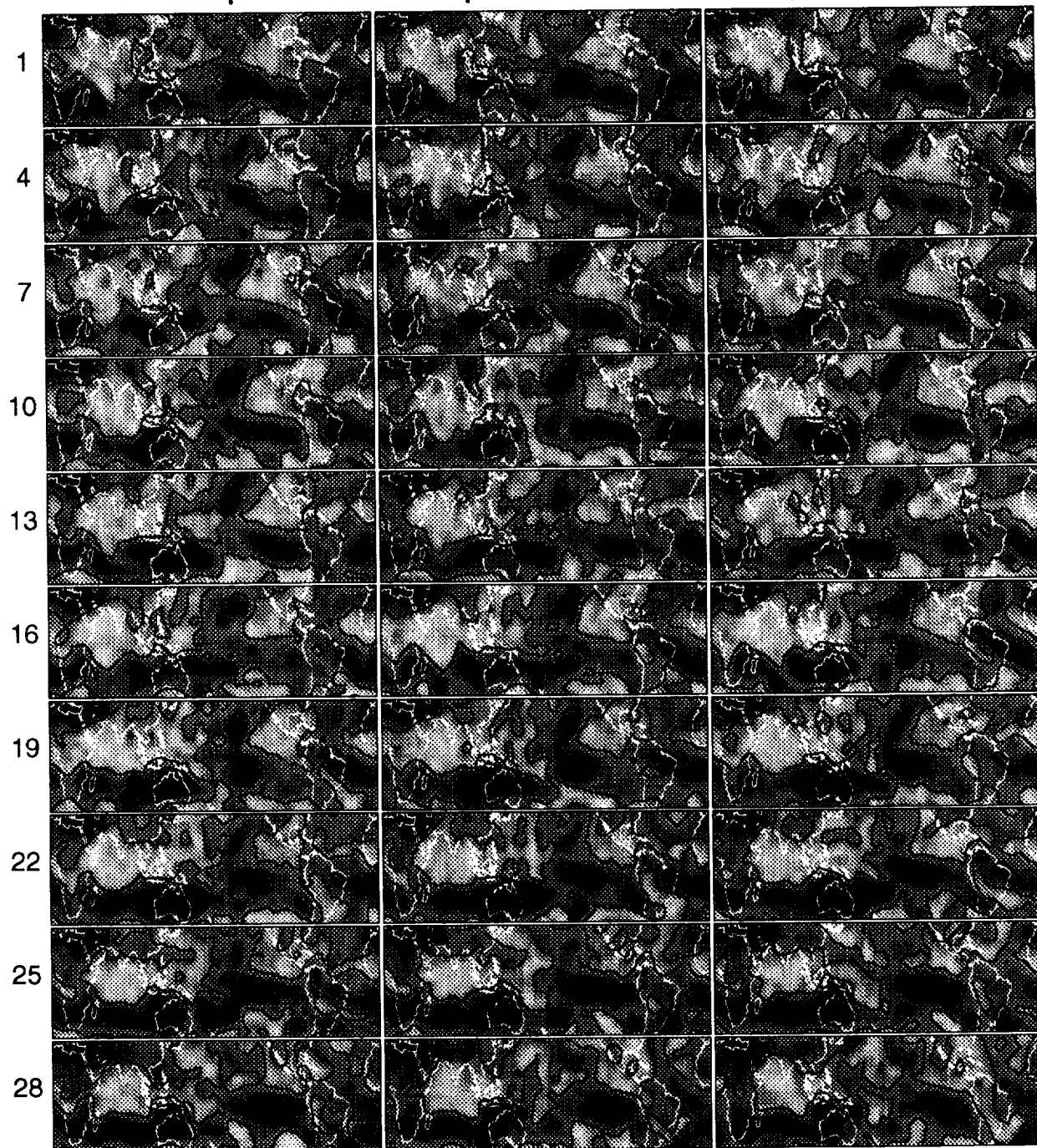
TOVS 6.5 μ m Water Vapor Band

August 1983



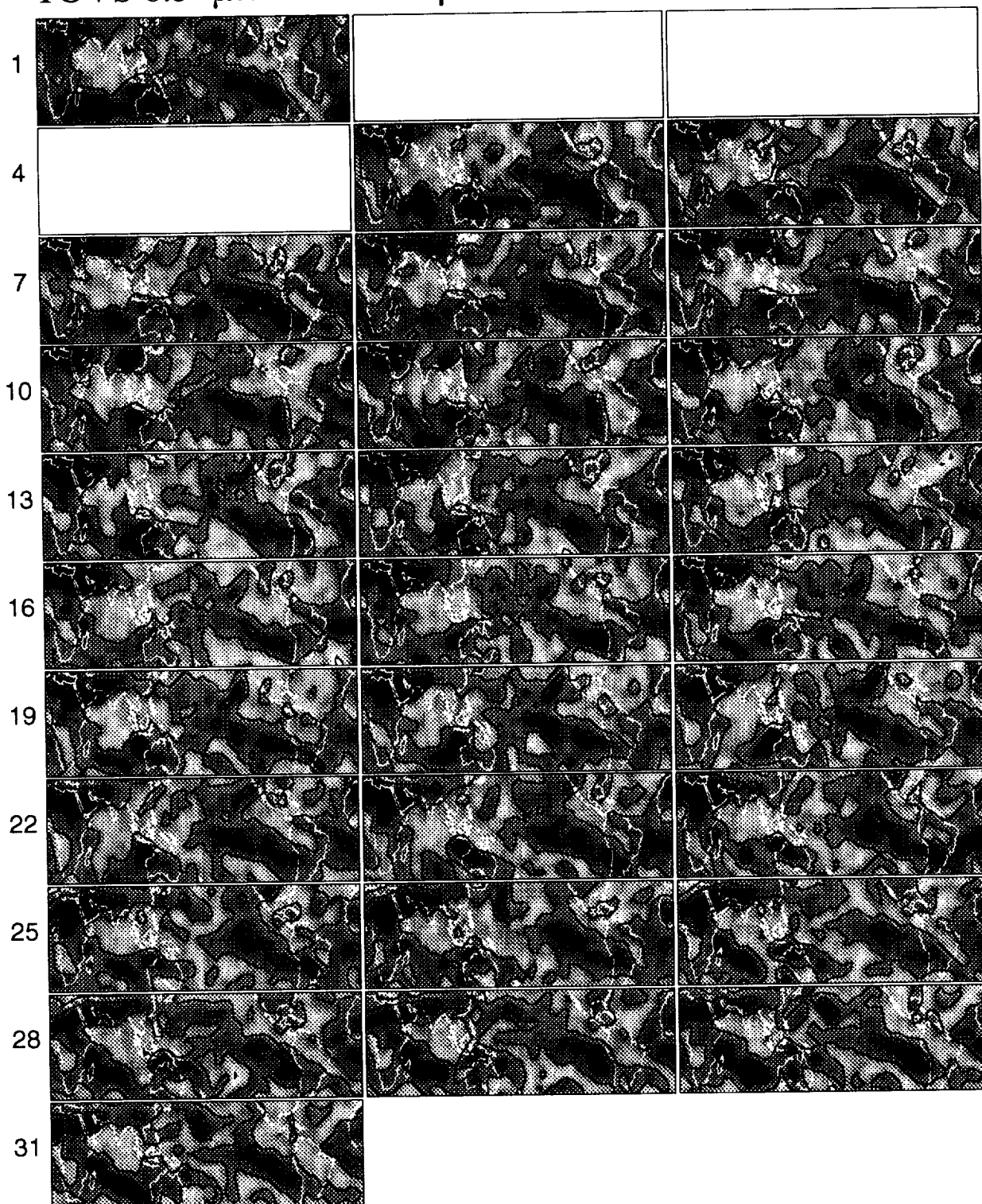
TOVS 6.5 μm Water Vapor Band

September 1983



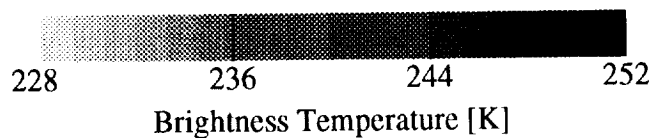
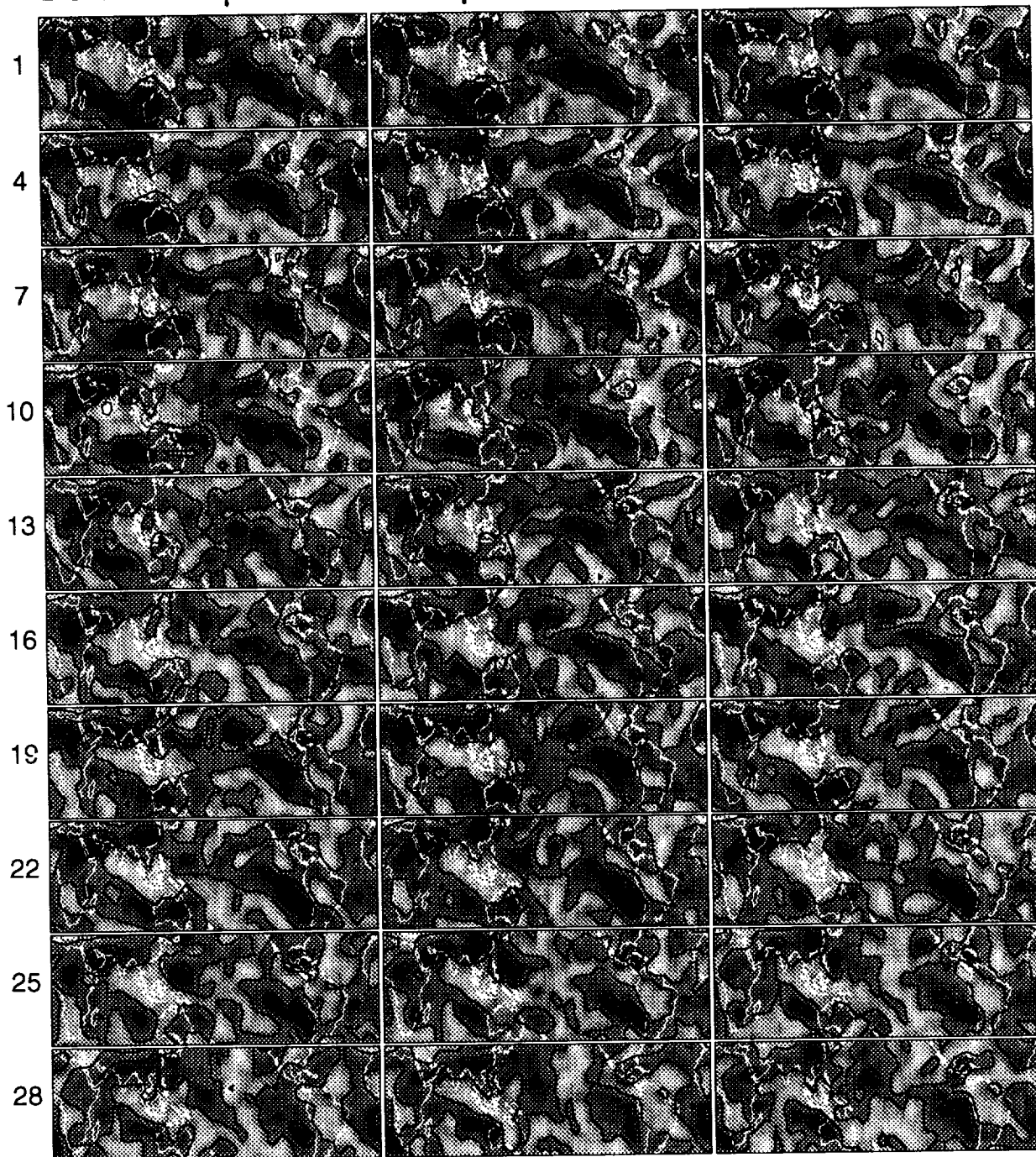
TOVS 6.5 μm Water Vapor Band

October 1983



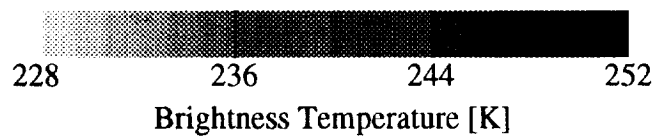
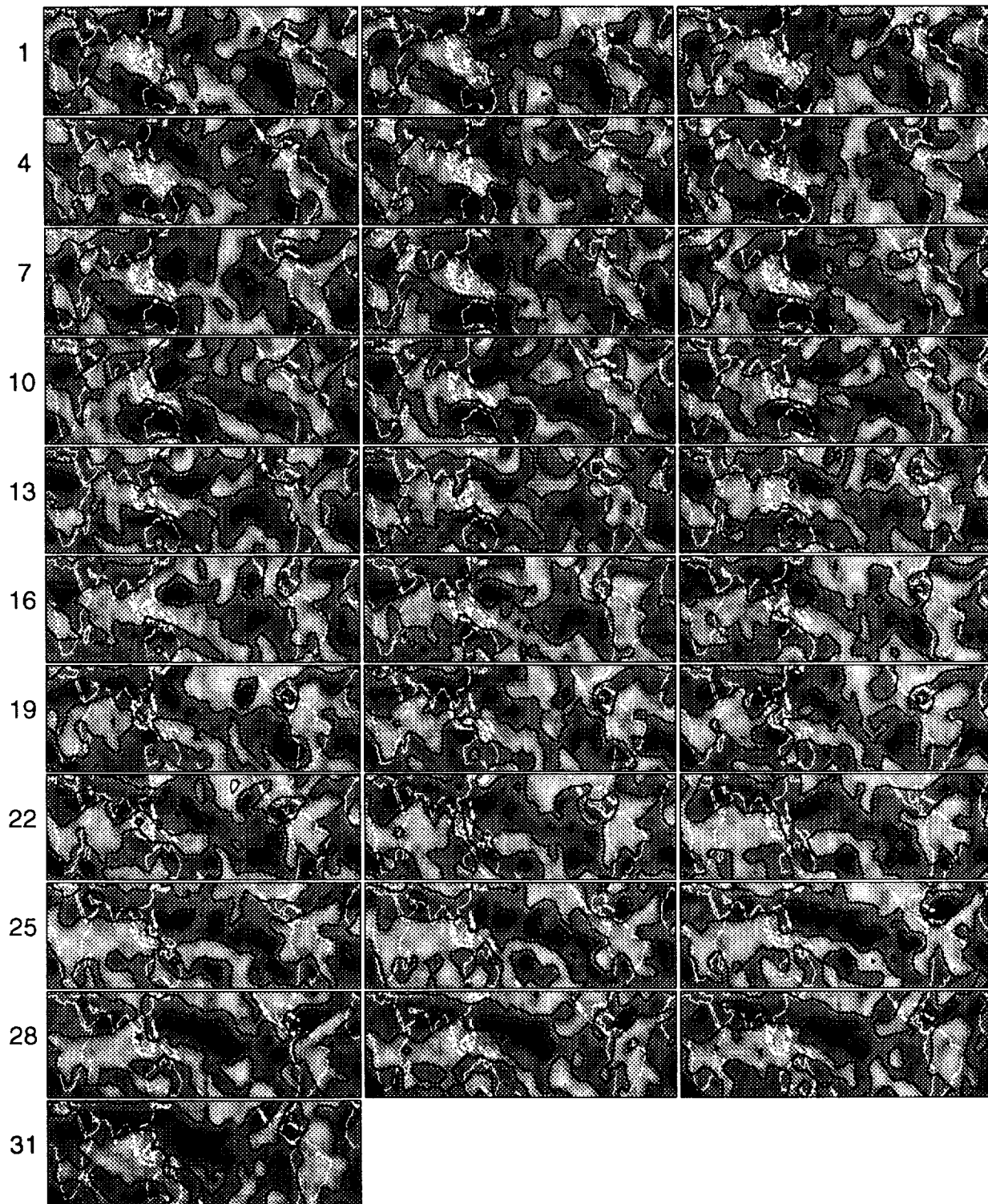
TOVS 6.5 μm Water Vapor Band

November 1983



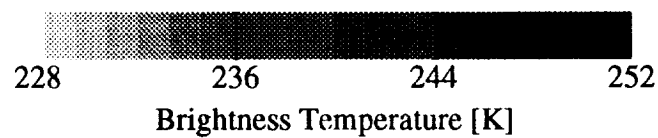
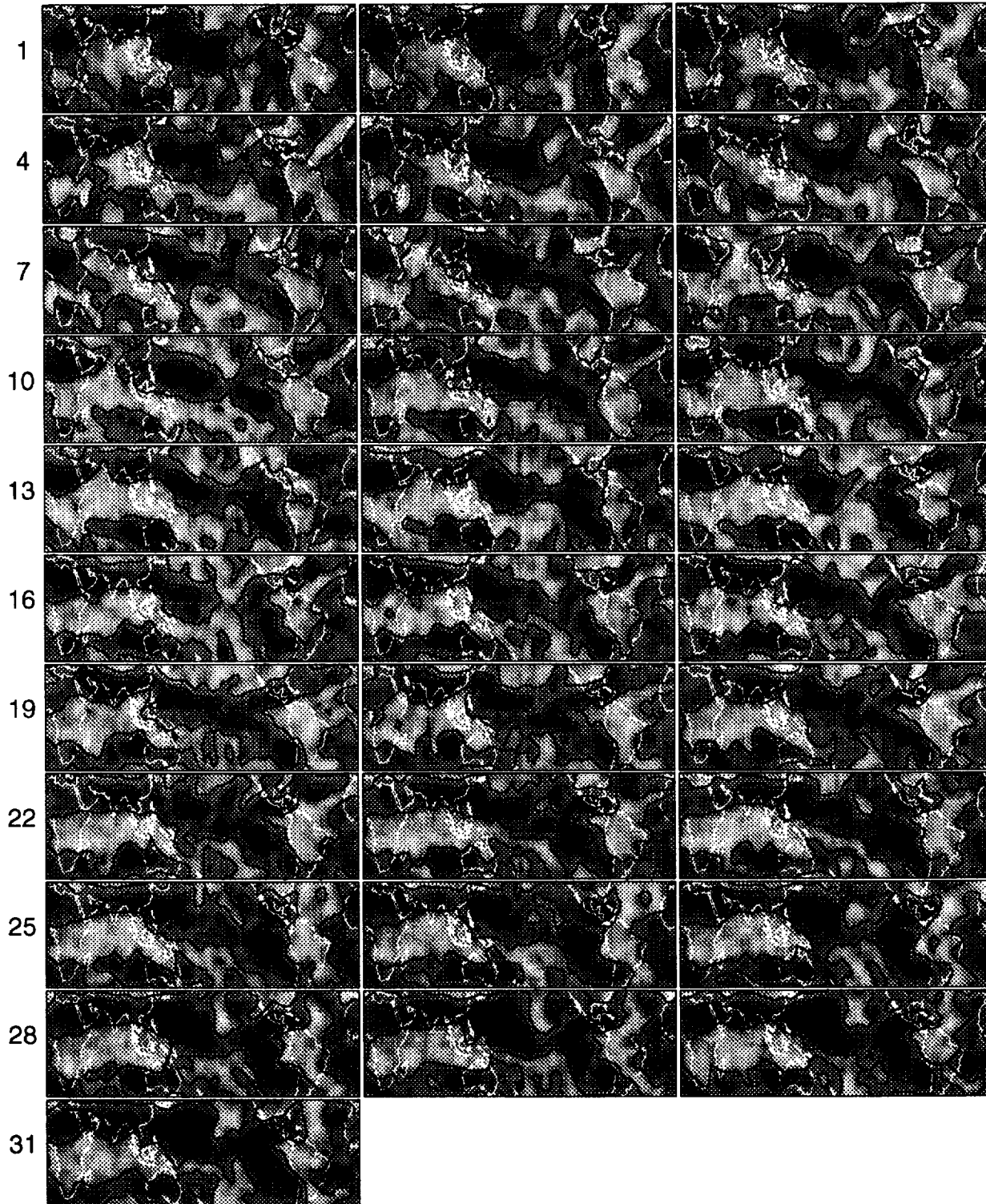
TOVS 6.5 μm Water Vapor Band

December 1983



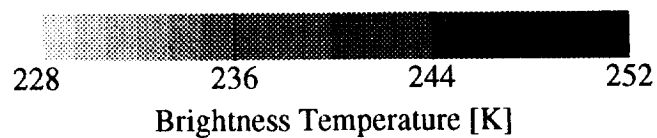
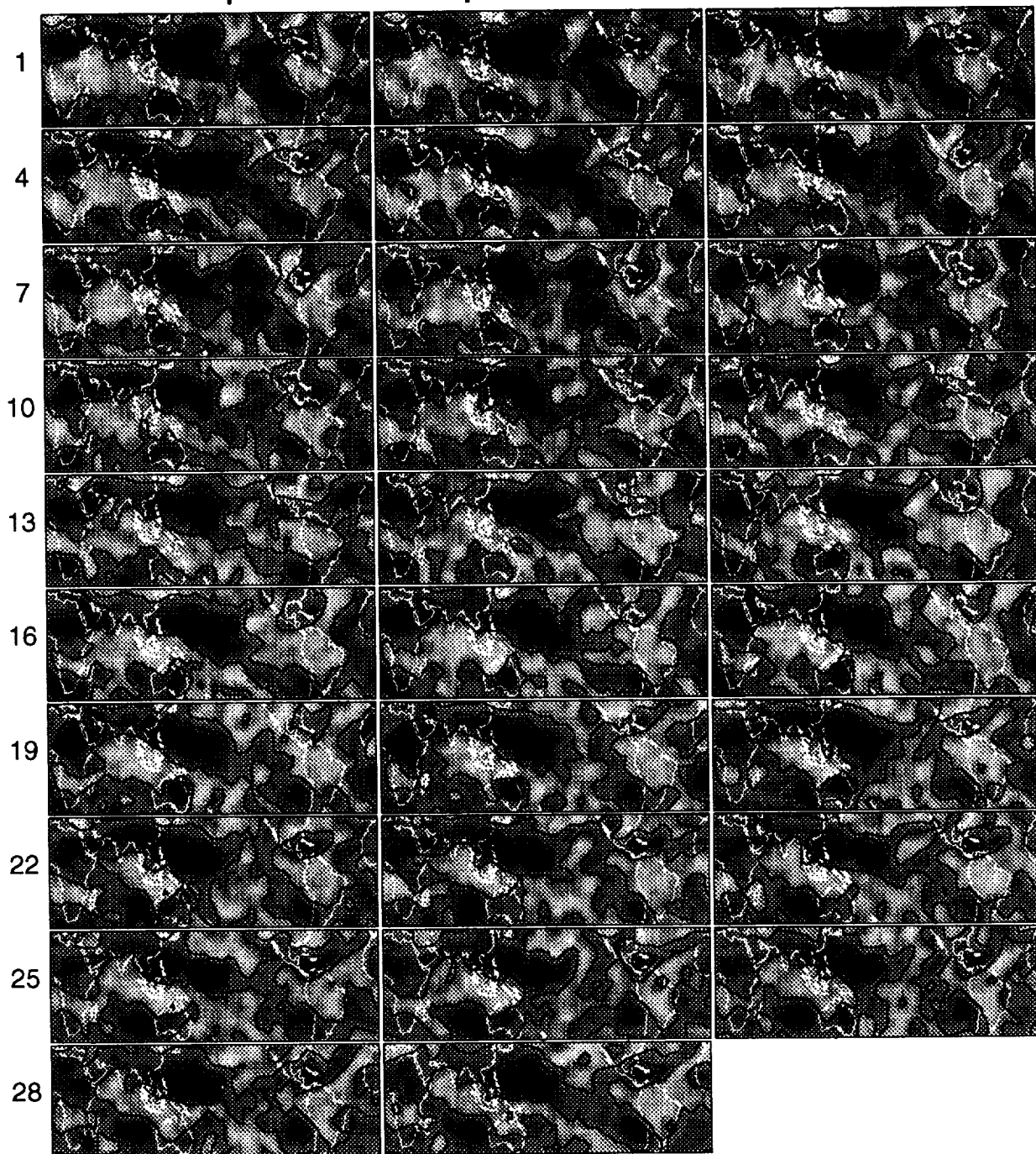
TOVS 6.5 μm Water Vapor Band

January 1984



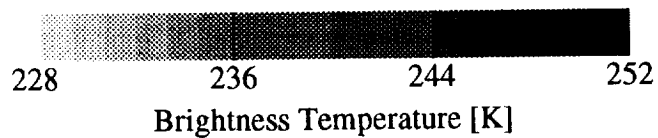
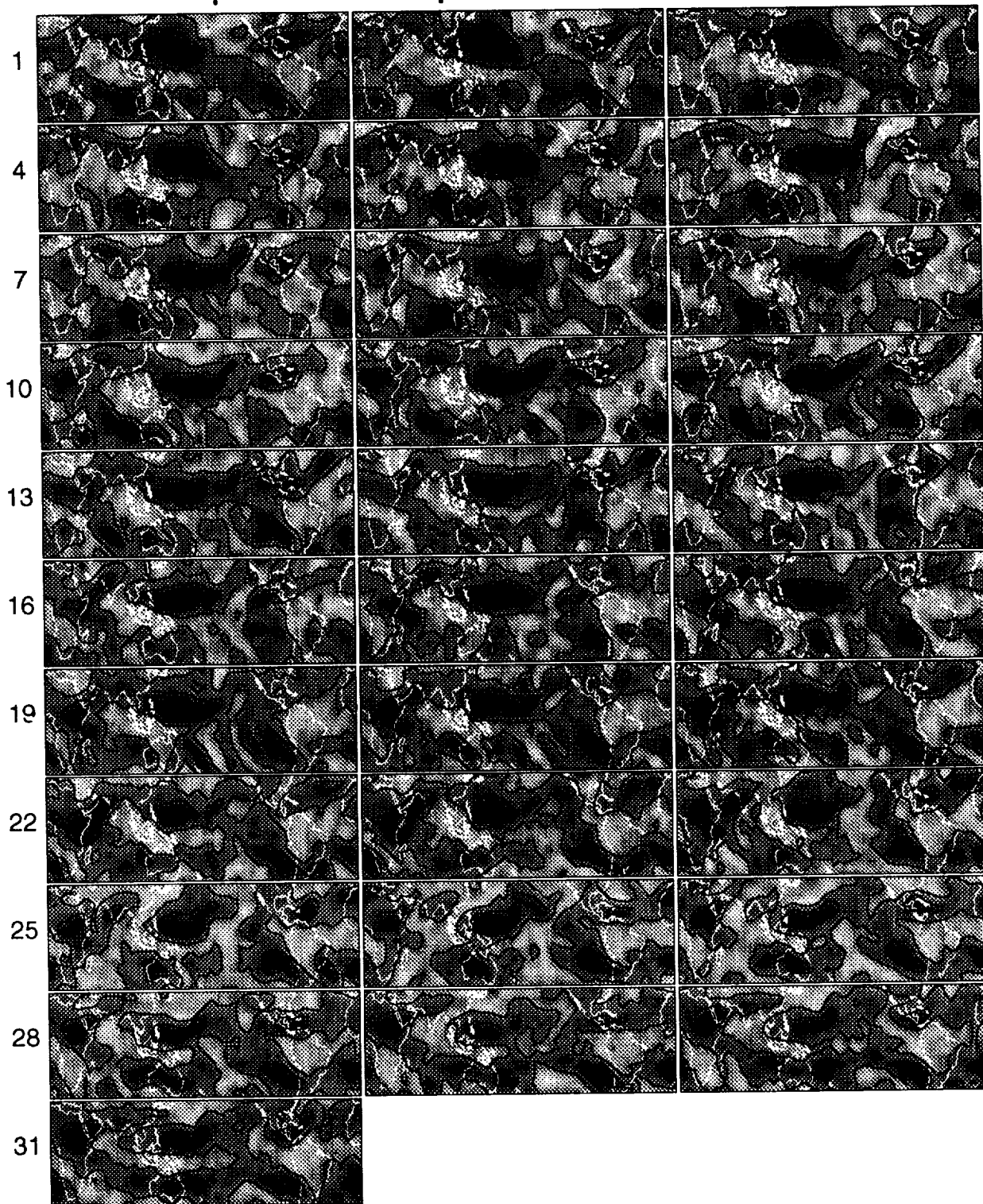
TOVS 6.5 μm Water Vapor Band

February 1984



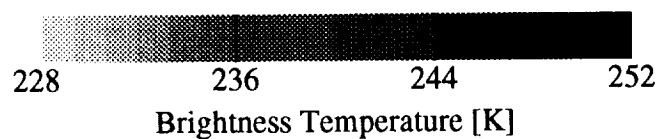
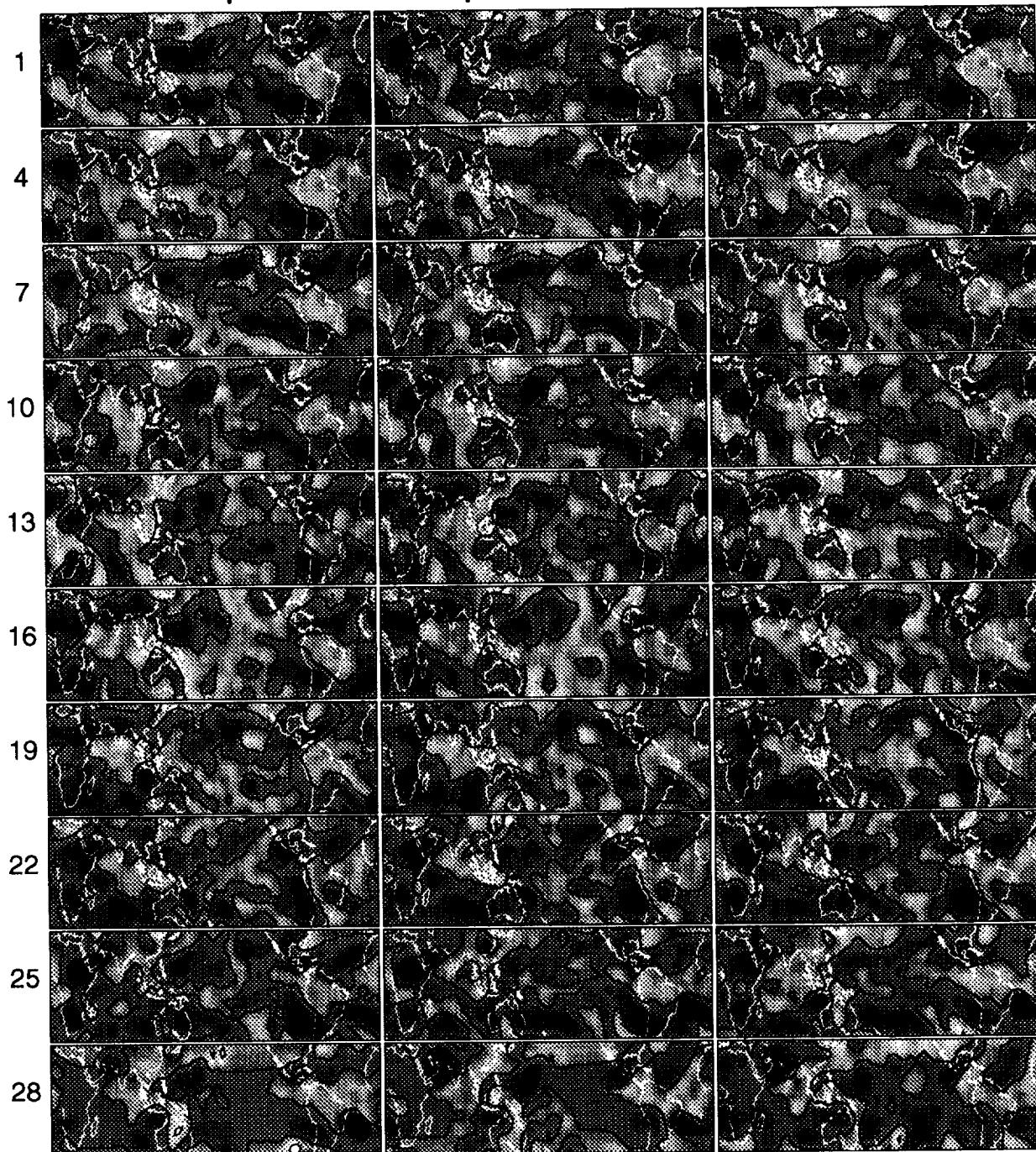
TOVS 6.5 μm Water Vapor Band

March 1984



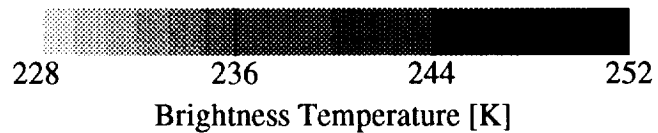
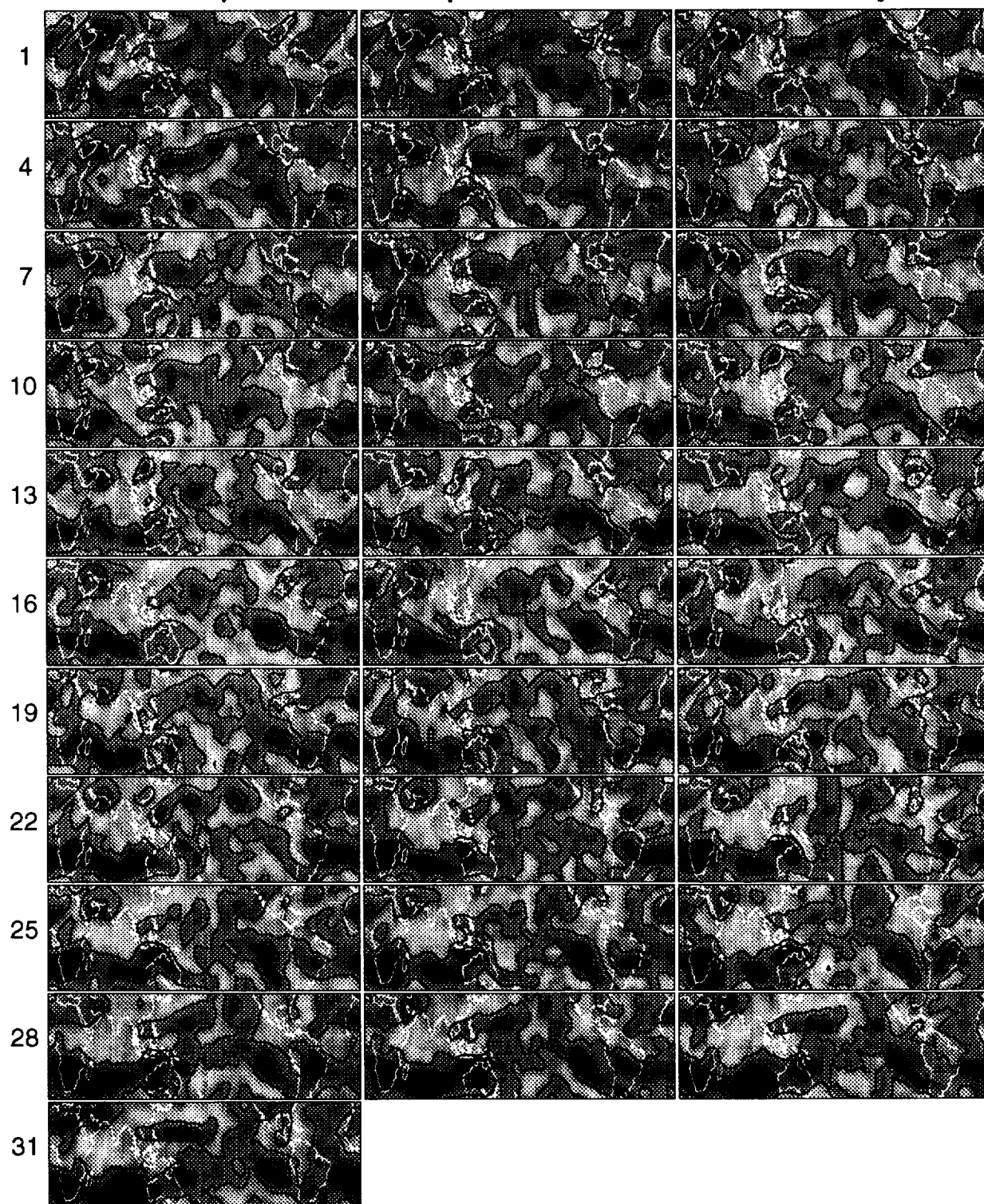
TOVS 6.5 μm Water Vapor Band

April 1984



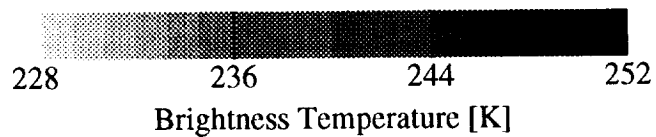
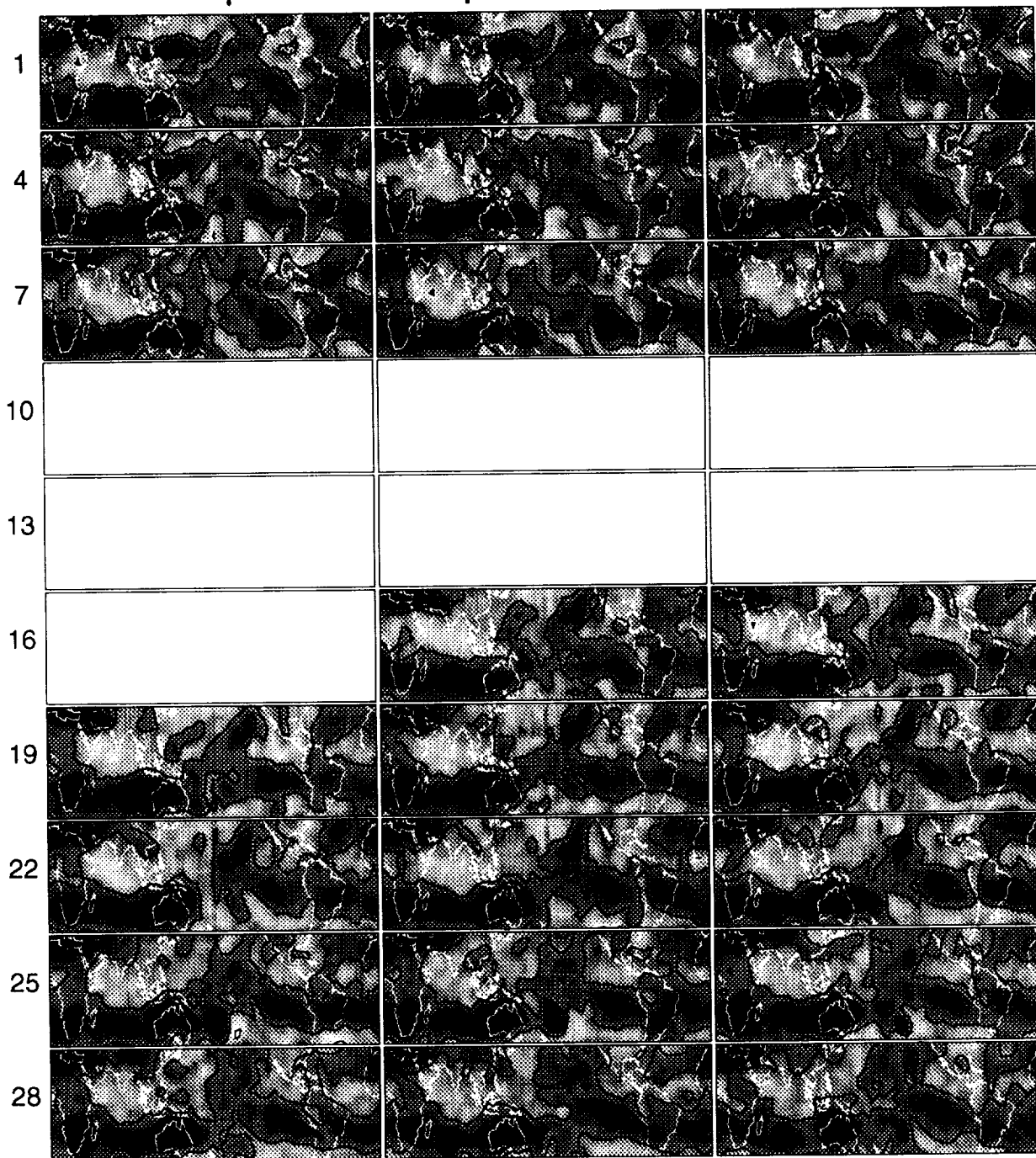
TOVS 6.5 μm Water Vapor Band

May 1984



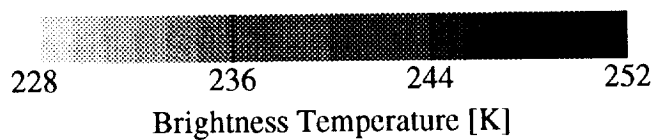
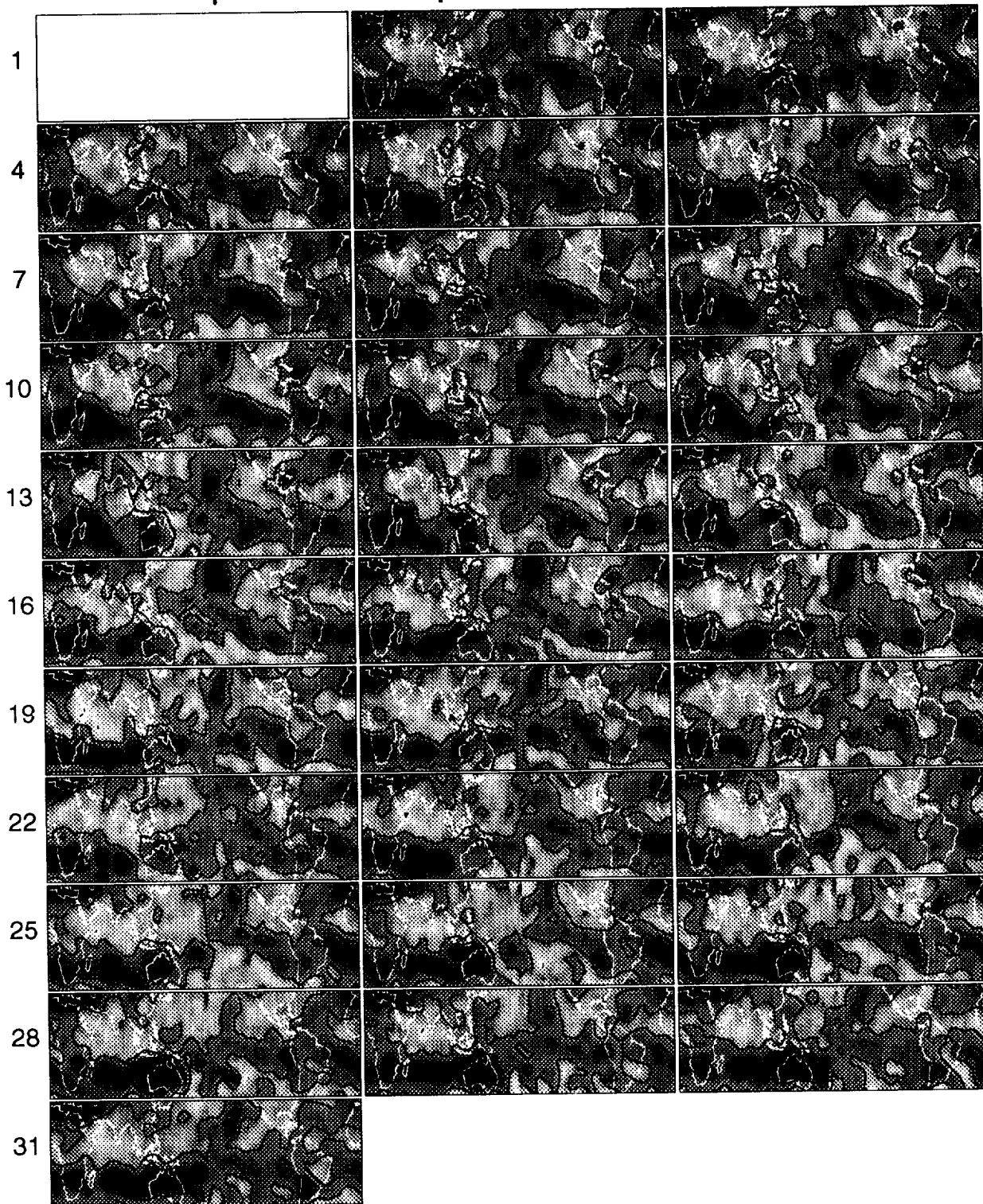
TOVS 6.5 μm Water Vapor Band

June 1984



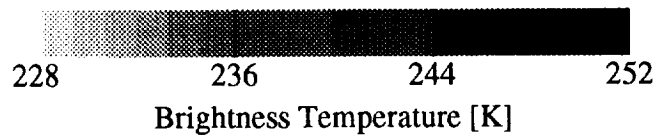
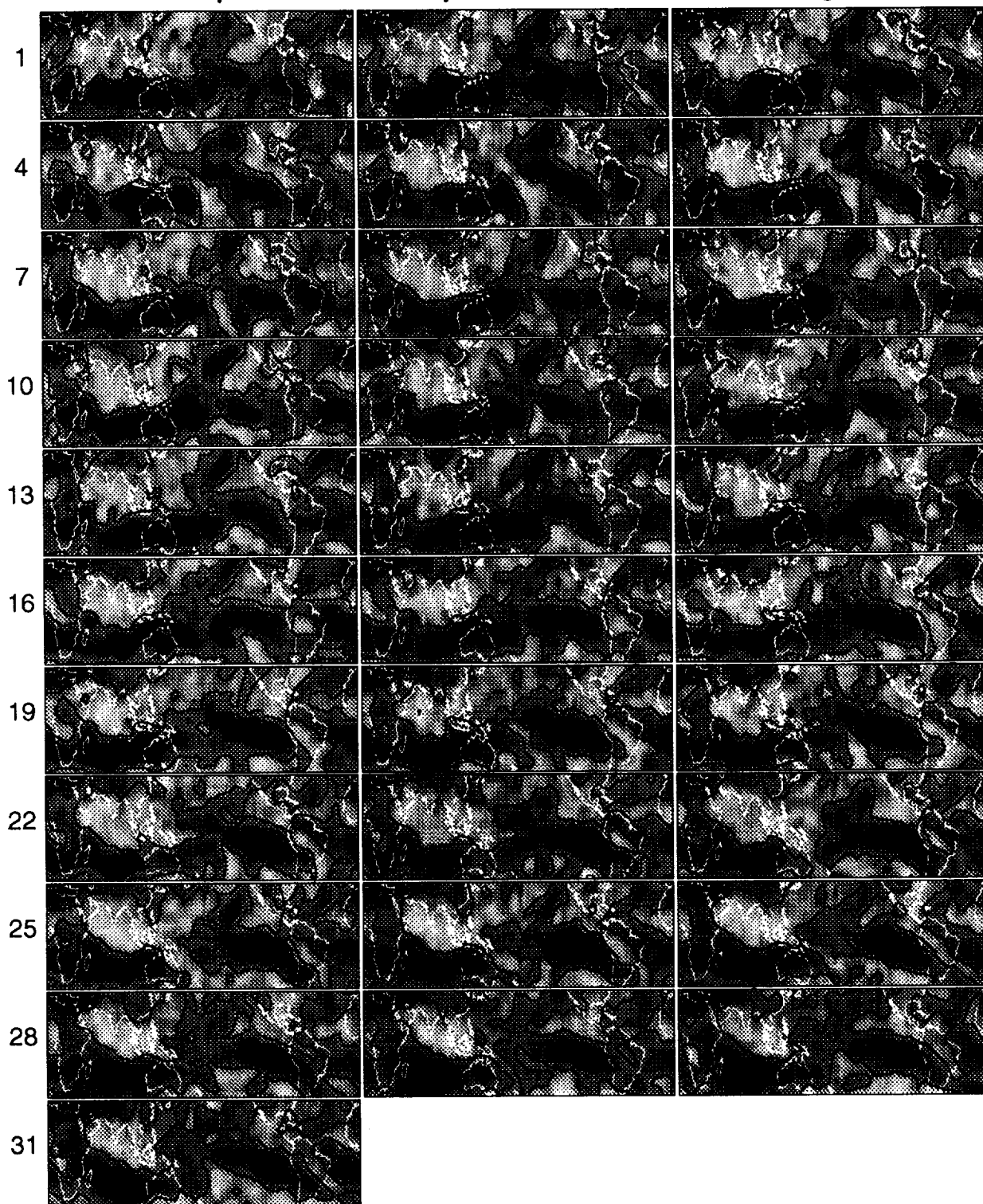
TOVS 6.5 μm Water Vapor Band

July 1984



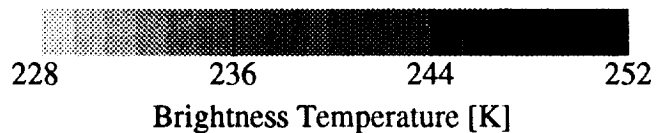
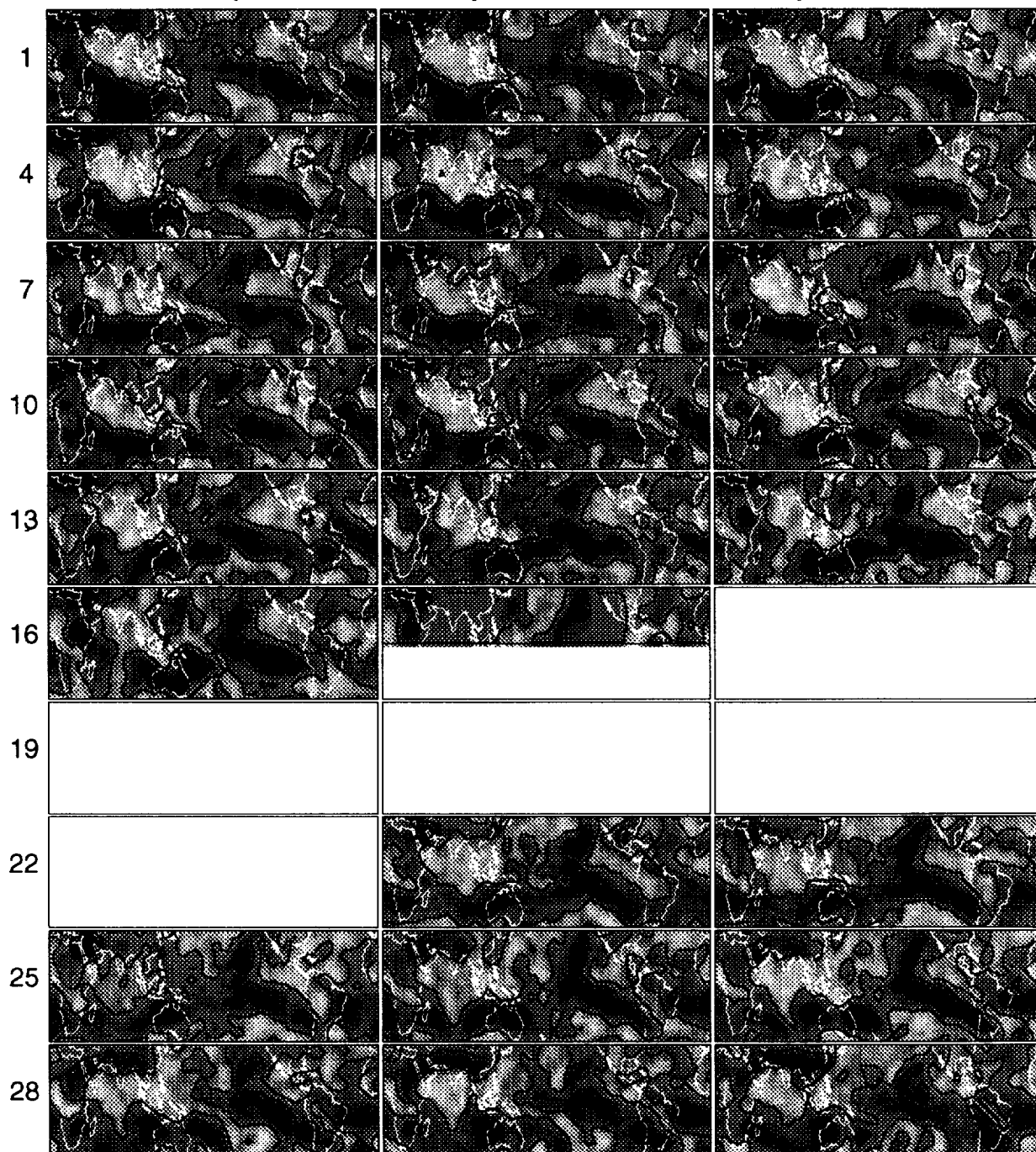
TOVS 6.5 μm Water Vapor Band

August 1984



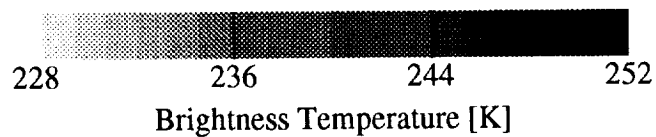
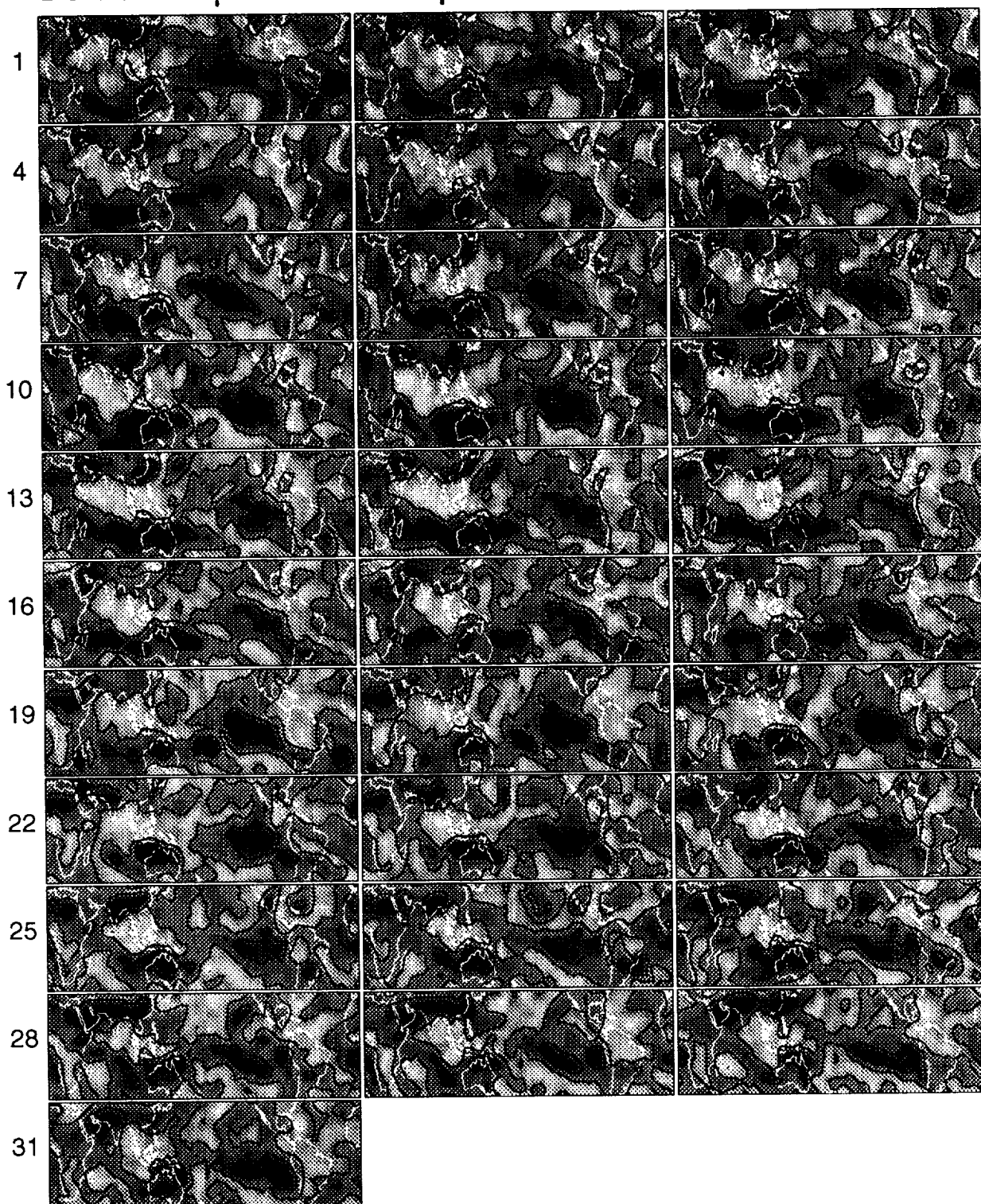
TOVS 6.5 μm Water Vapor Band

September 1984



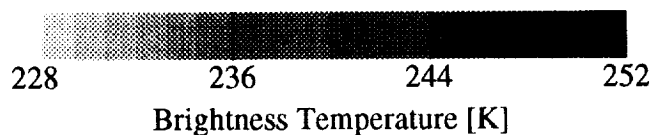
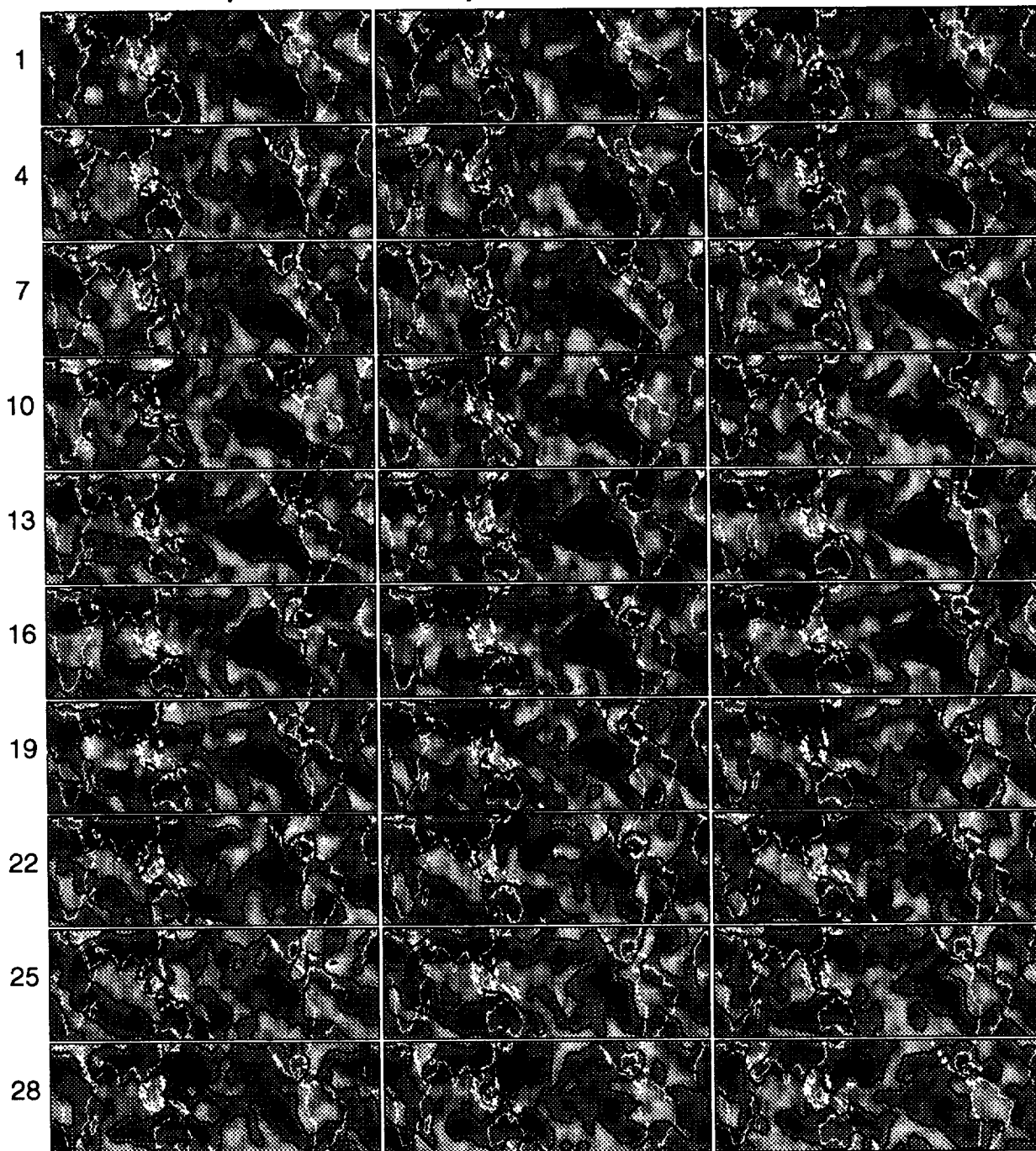
TOVS 6.5 μm Water Vapor Band

October 1984



TOVS 6.5 μm Water Vapor Band

November 1984



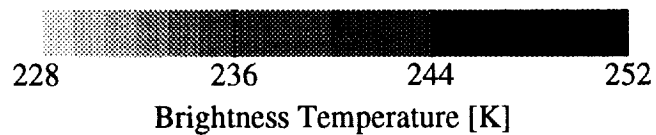
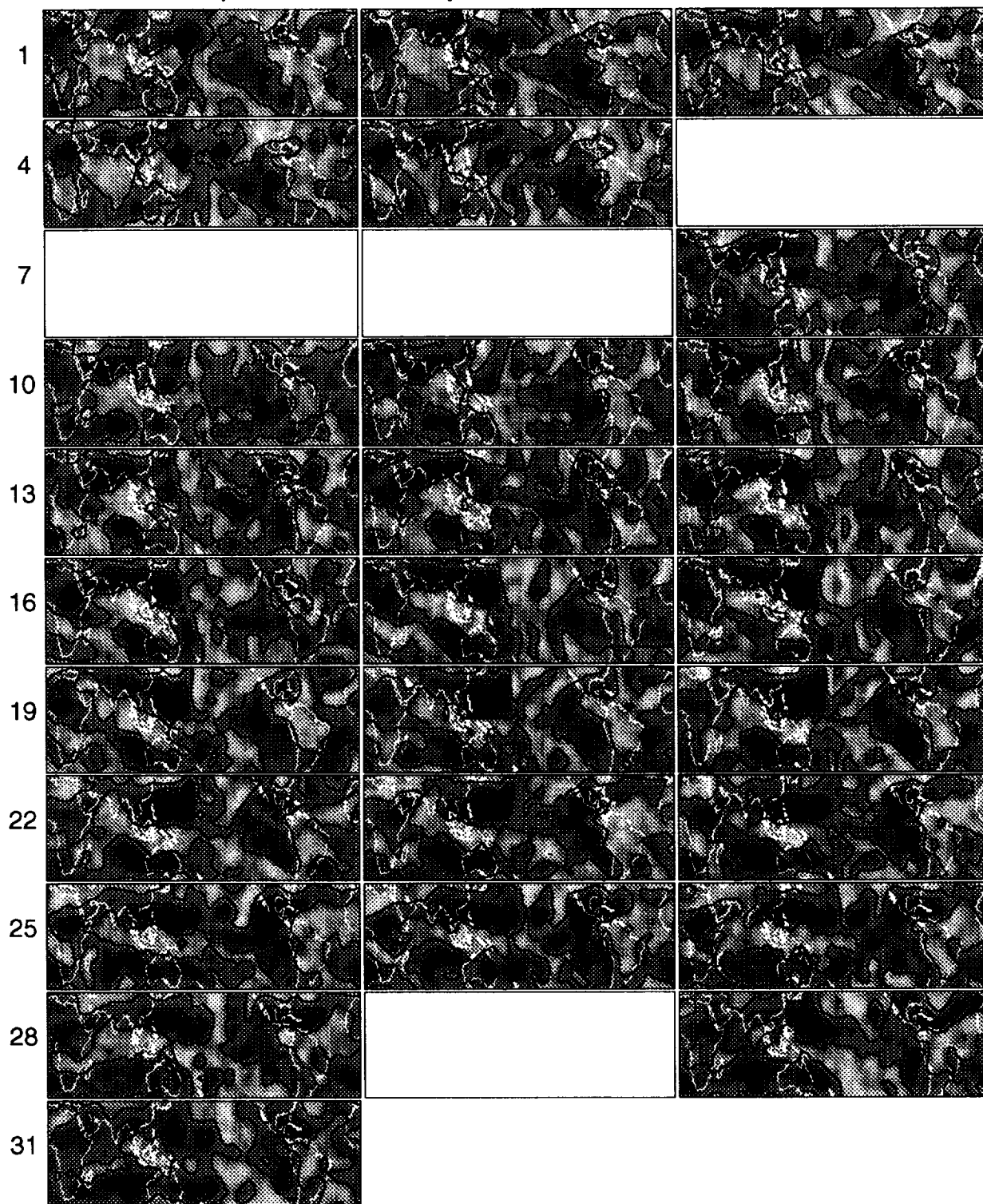
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A-143

NOVEMBER 1984

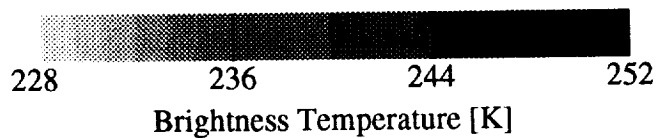
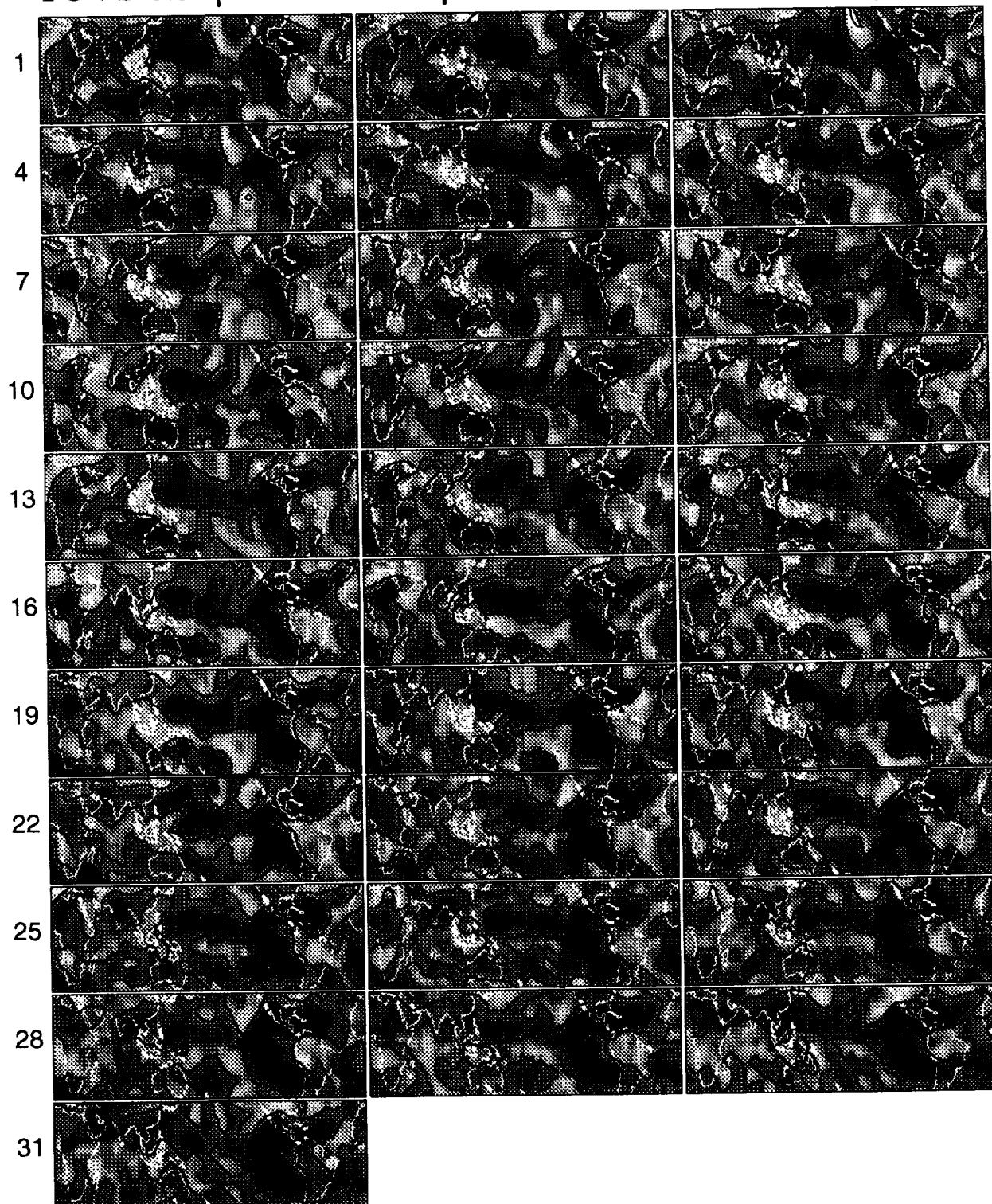
TOVS 6.5 μm Water Vapor Band

December 1984



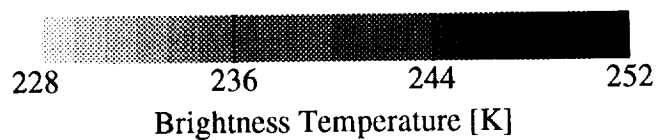
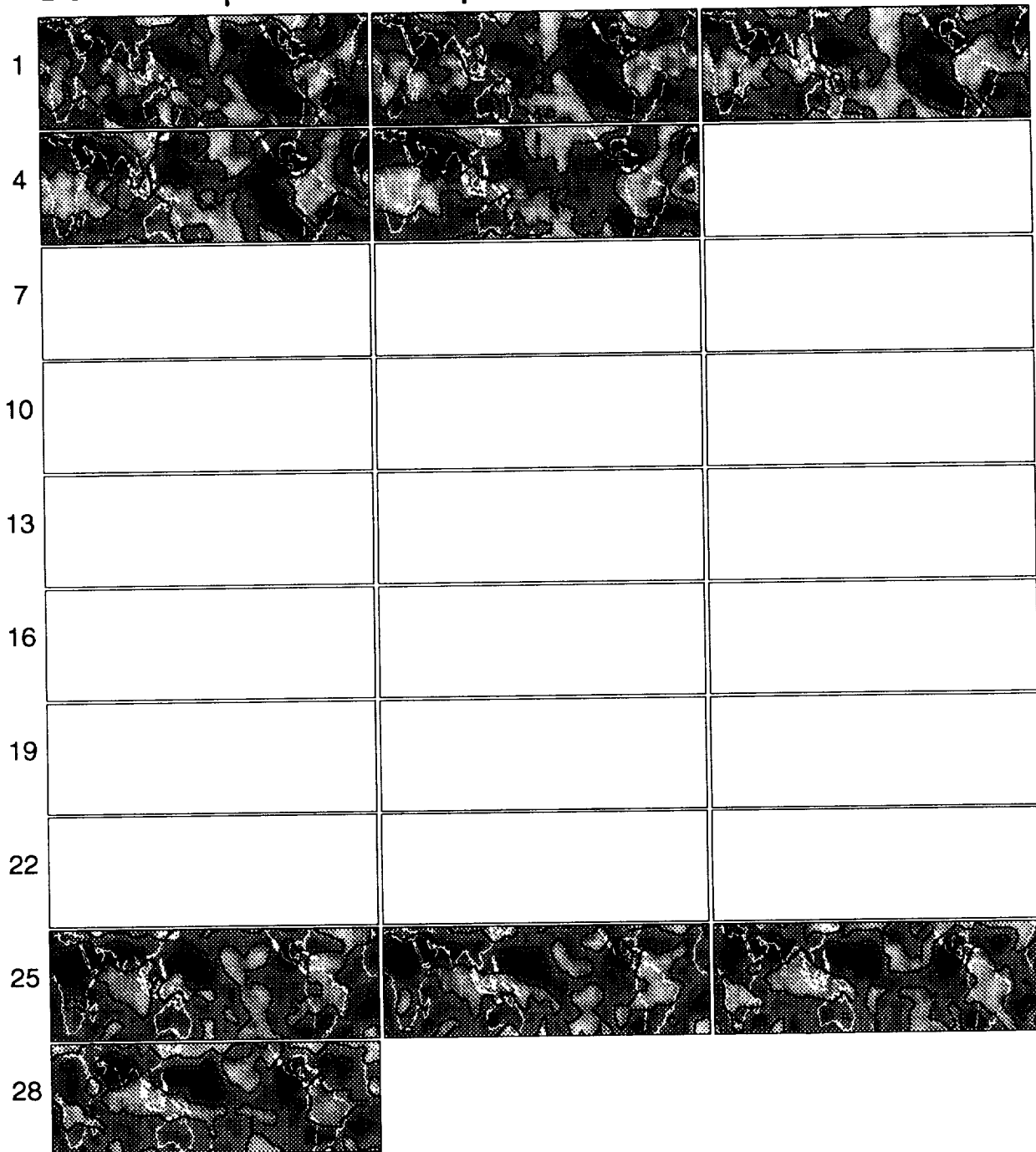
TOVS 6.5 μm Water Vapor Band

January 1985



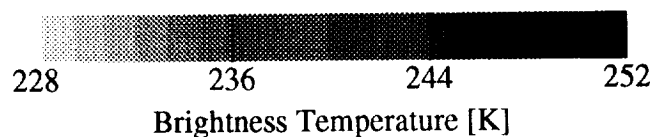
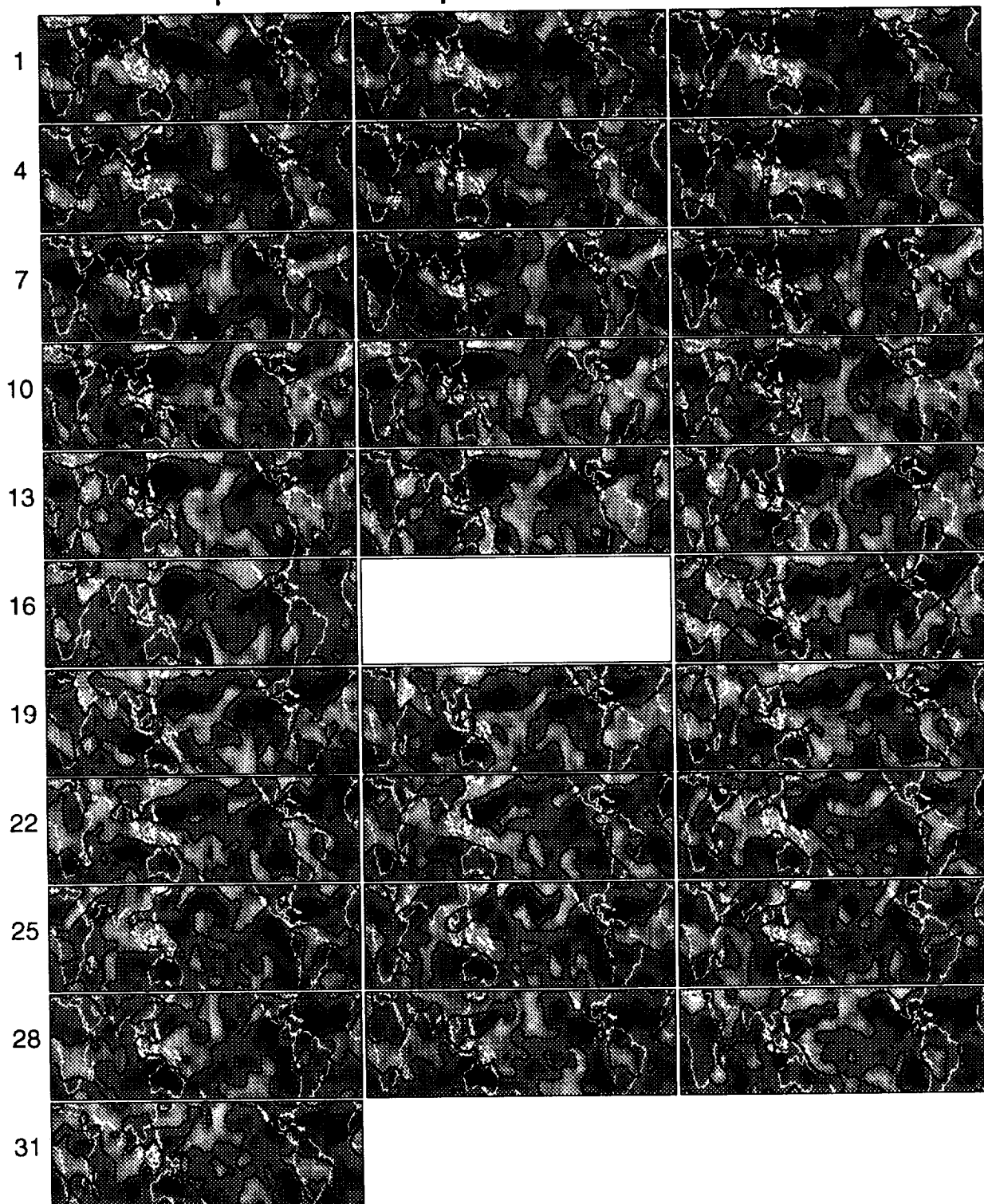
TOVS 6.5 μm Water Vapor Band

February 1985



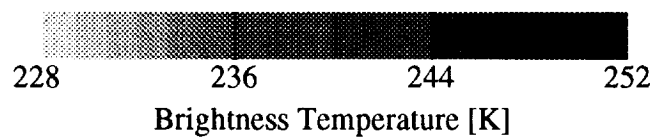
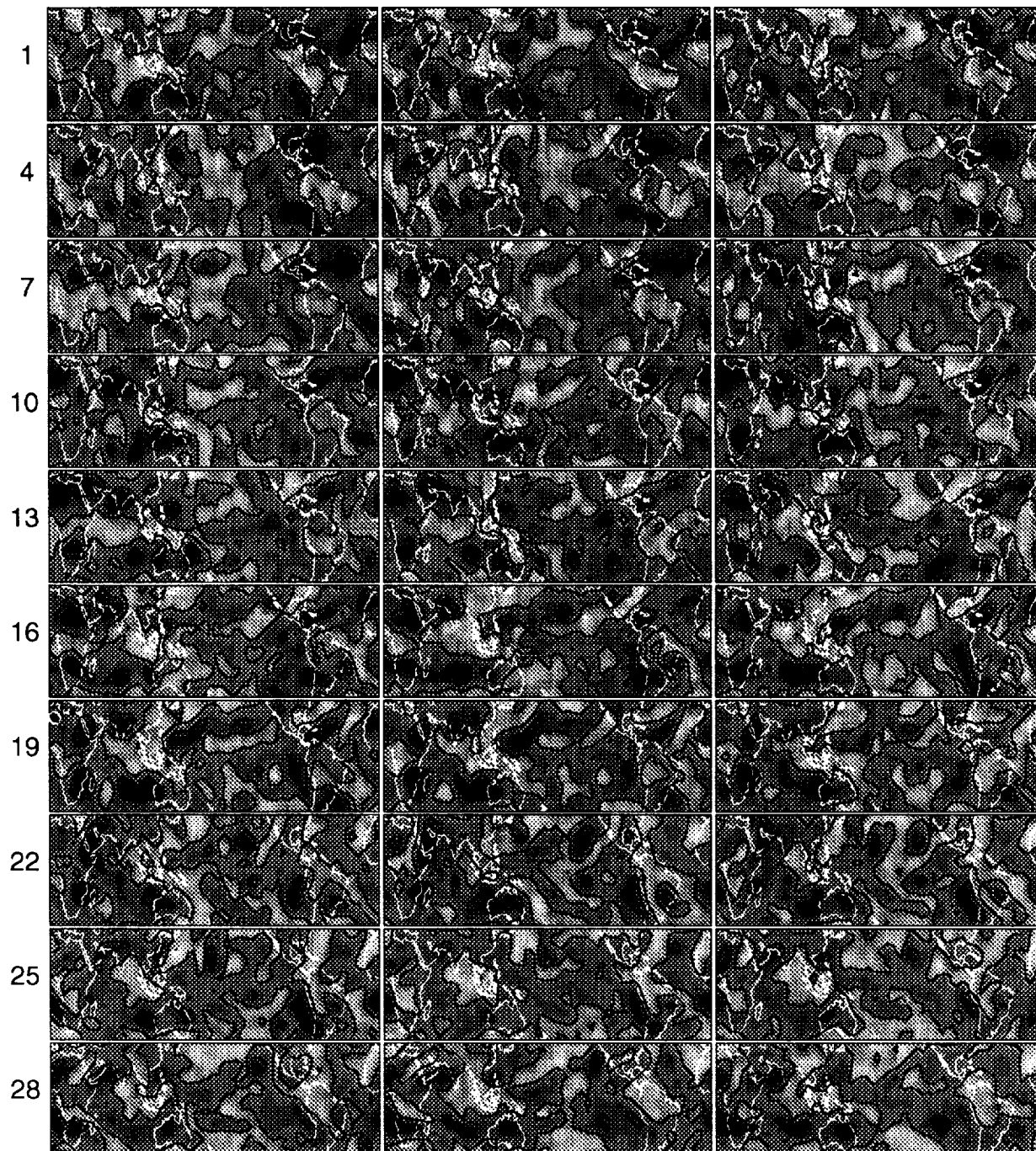
TOVS 6.5 μm Water Vapor Band

March 1985



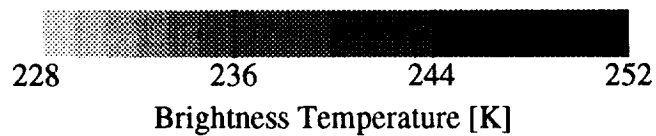
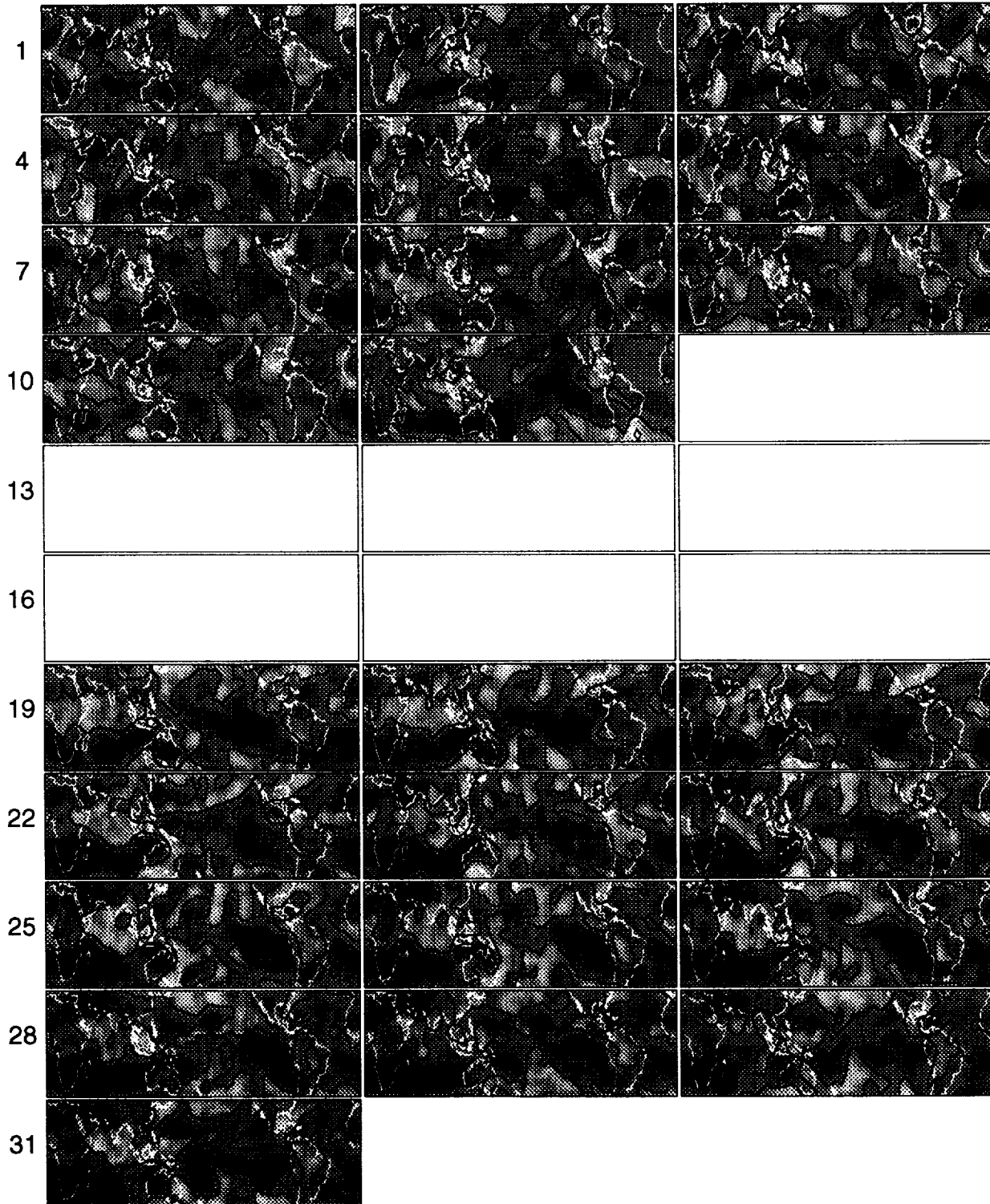
TOVS 6.5 μm Water Vapor Band

April 1985



TOVS 6.5 μm Water Vapor Band

May 1985



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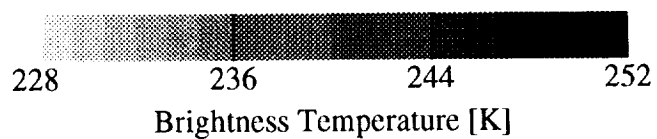
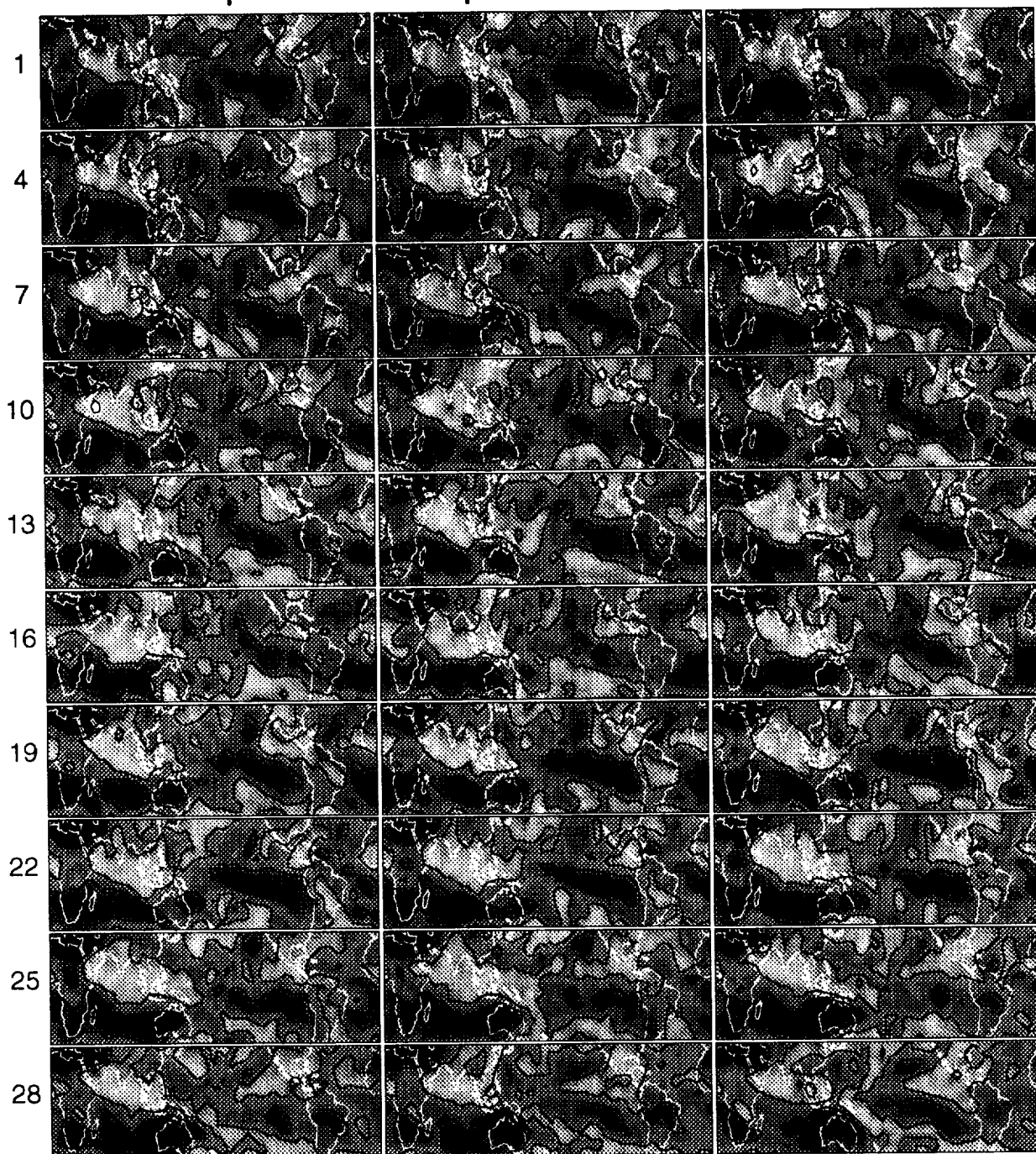
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C-2

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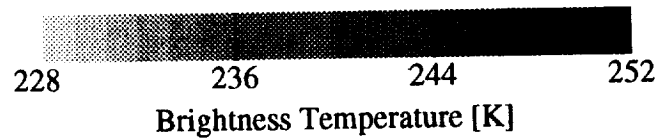
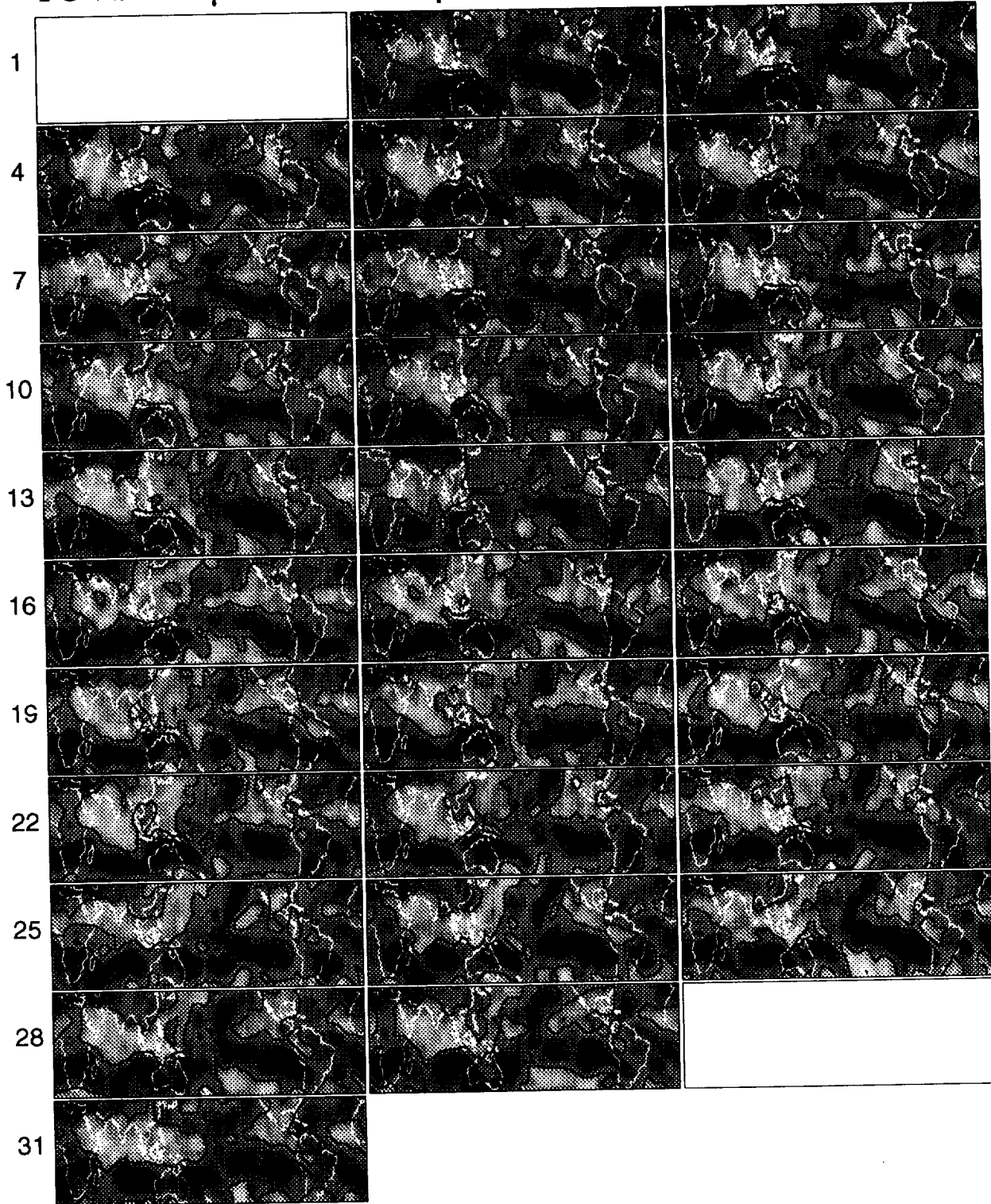
TOVS 6.5 μm Water Vapor Band

June 1985



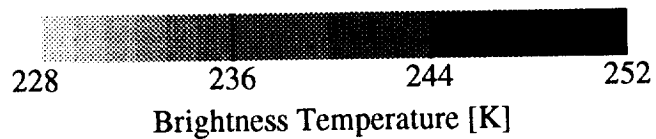
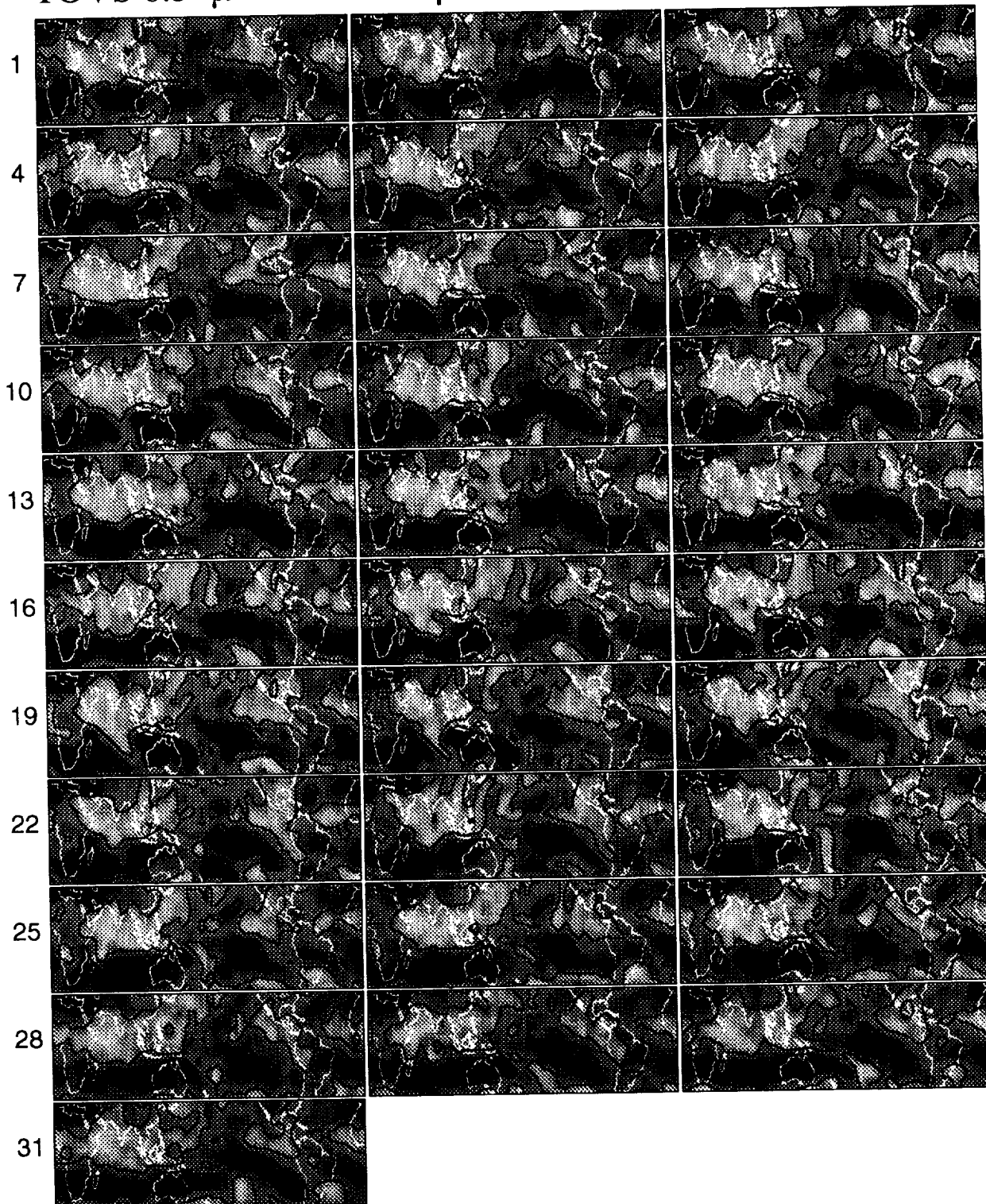
TOVS 6.5 μm Water Vapor Band

July 1985



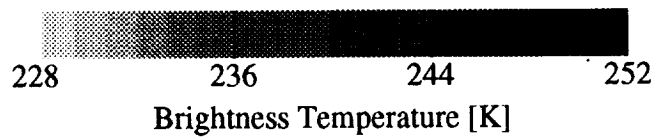
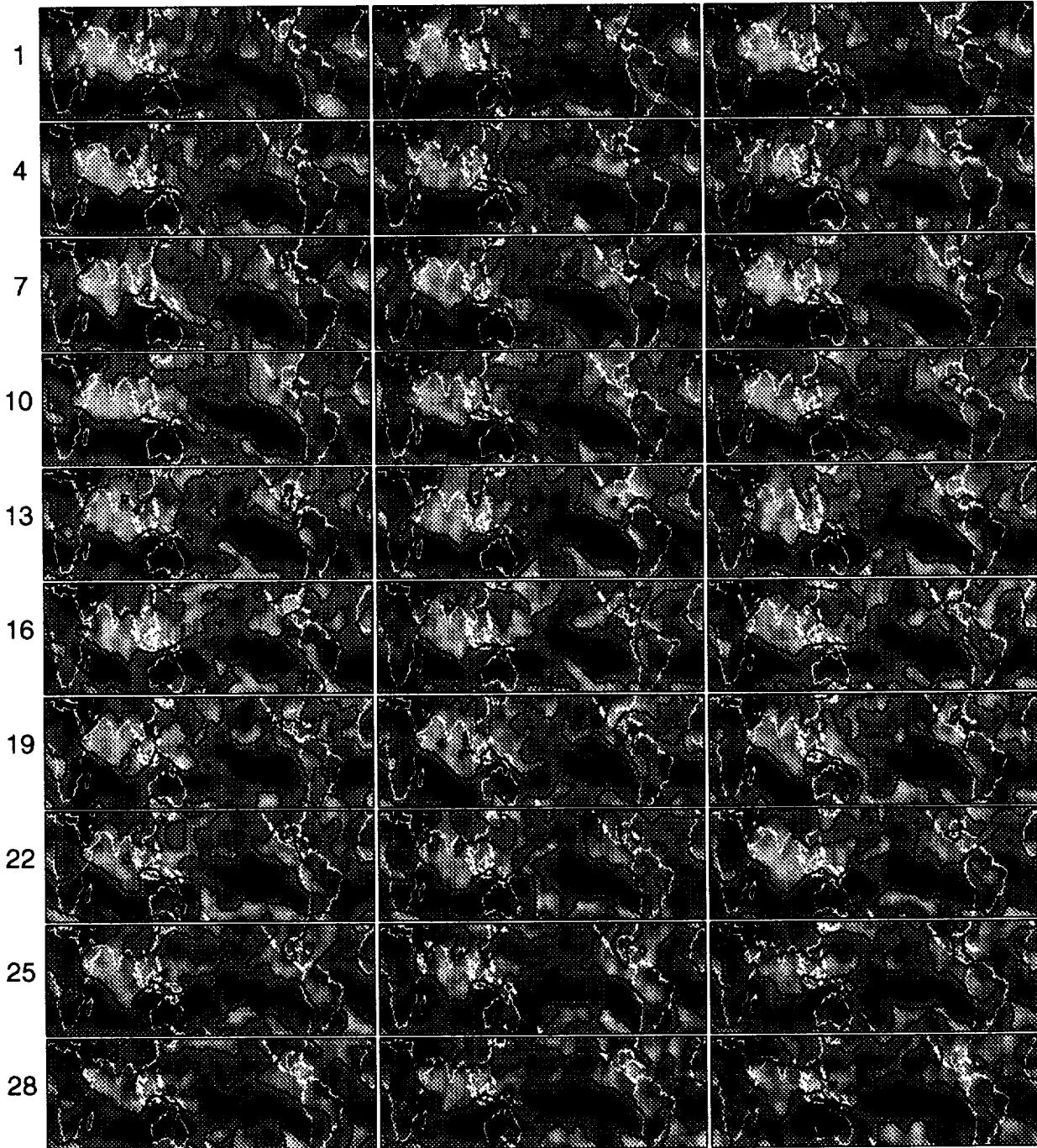
TOVS 6.5 μm Water Vapor Band

August 1985



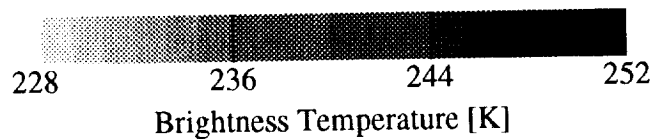
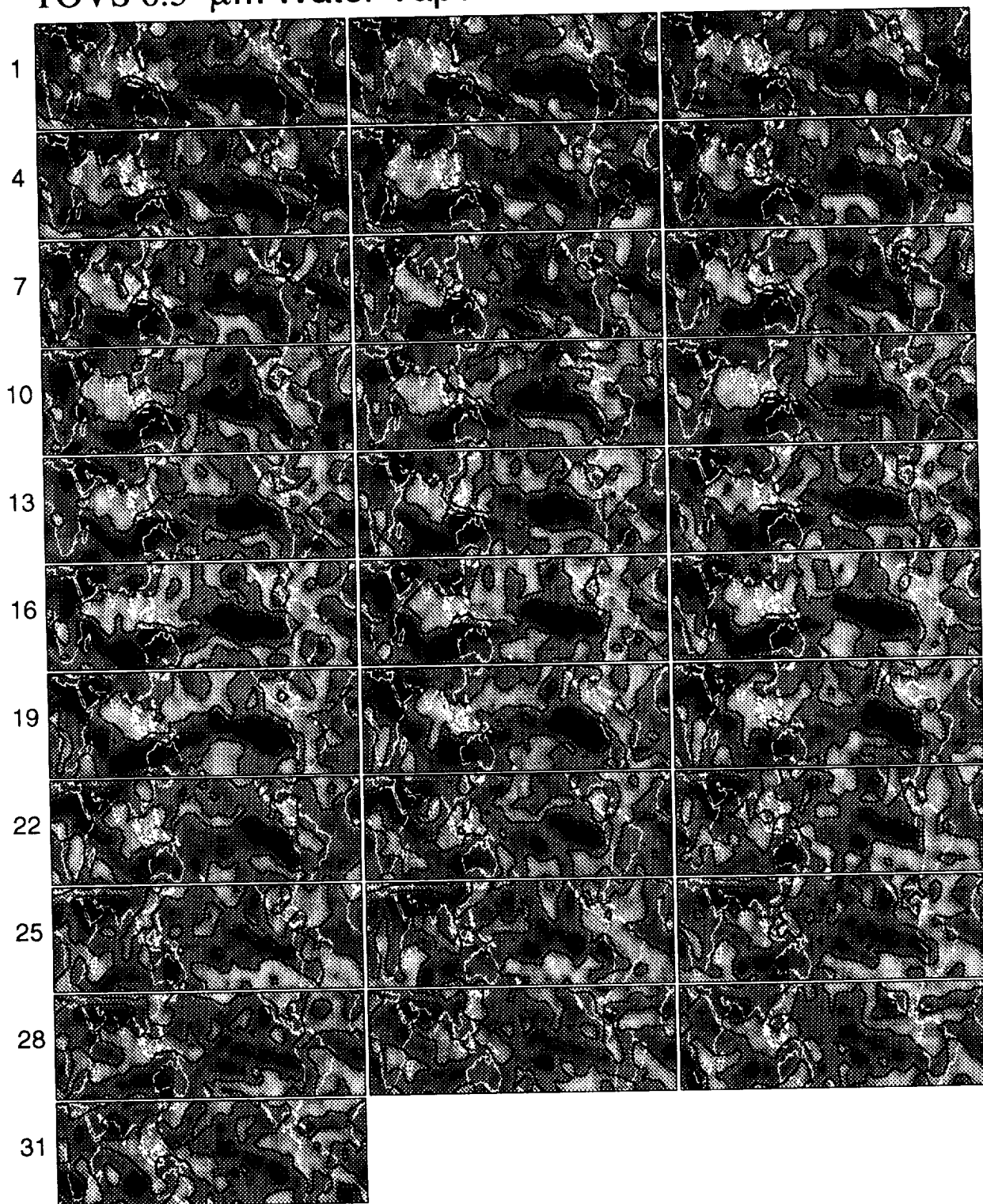
TOVS 6.5 μm Water Vapor Band

September 1985



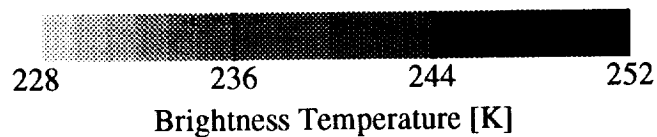
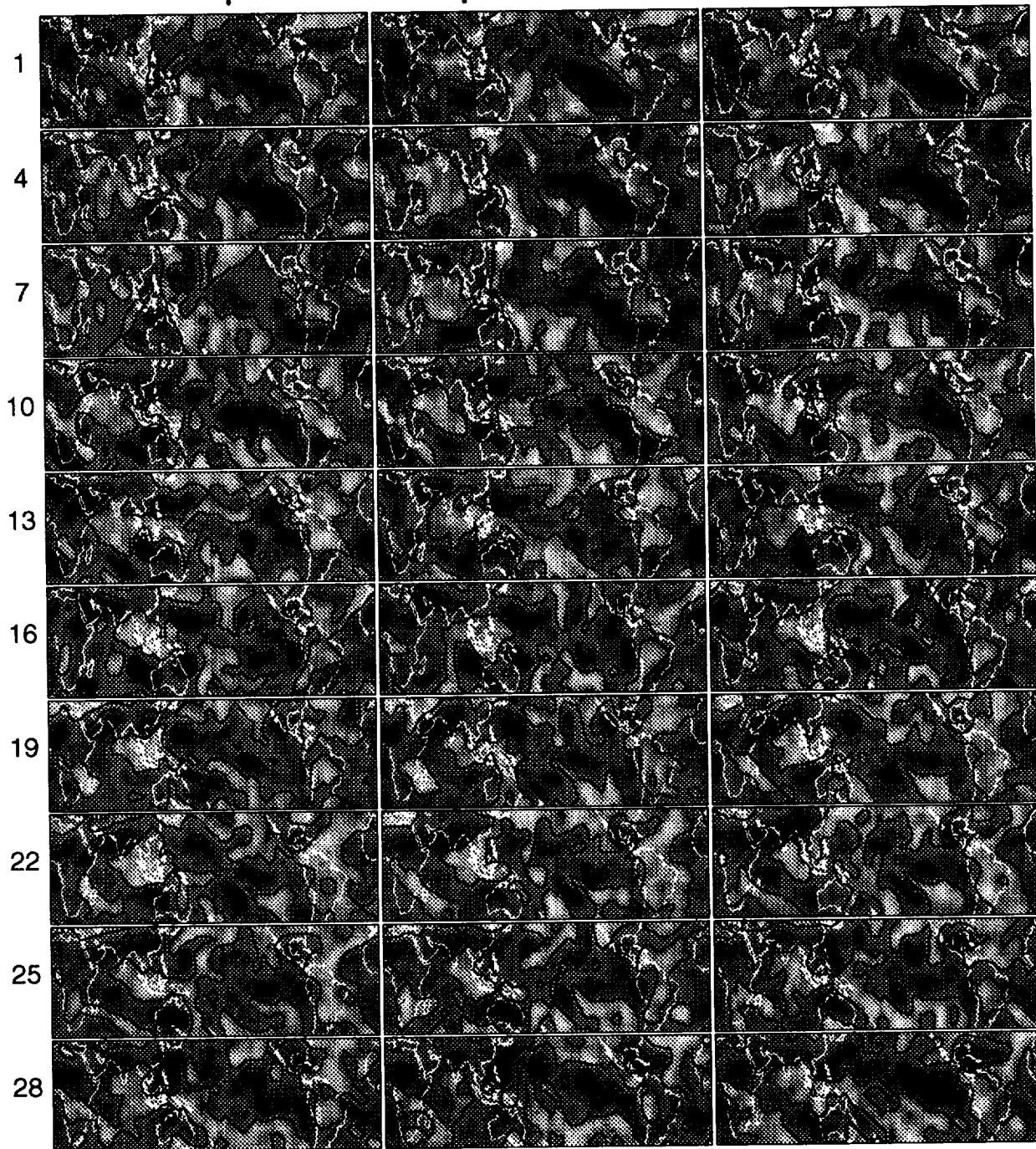
TOVS 6.5 μm Water Vapor Band

October 1985



TOVS 6.5 μm Water Vapor Band

November 1985

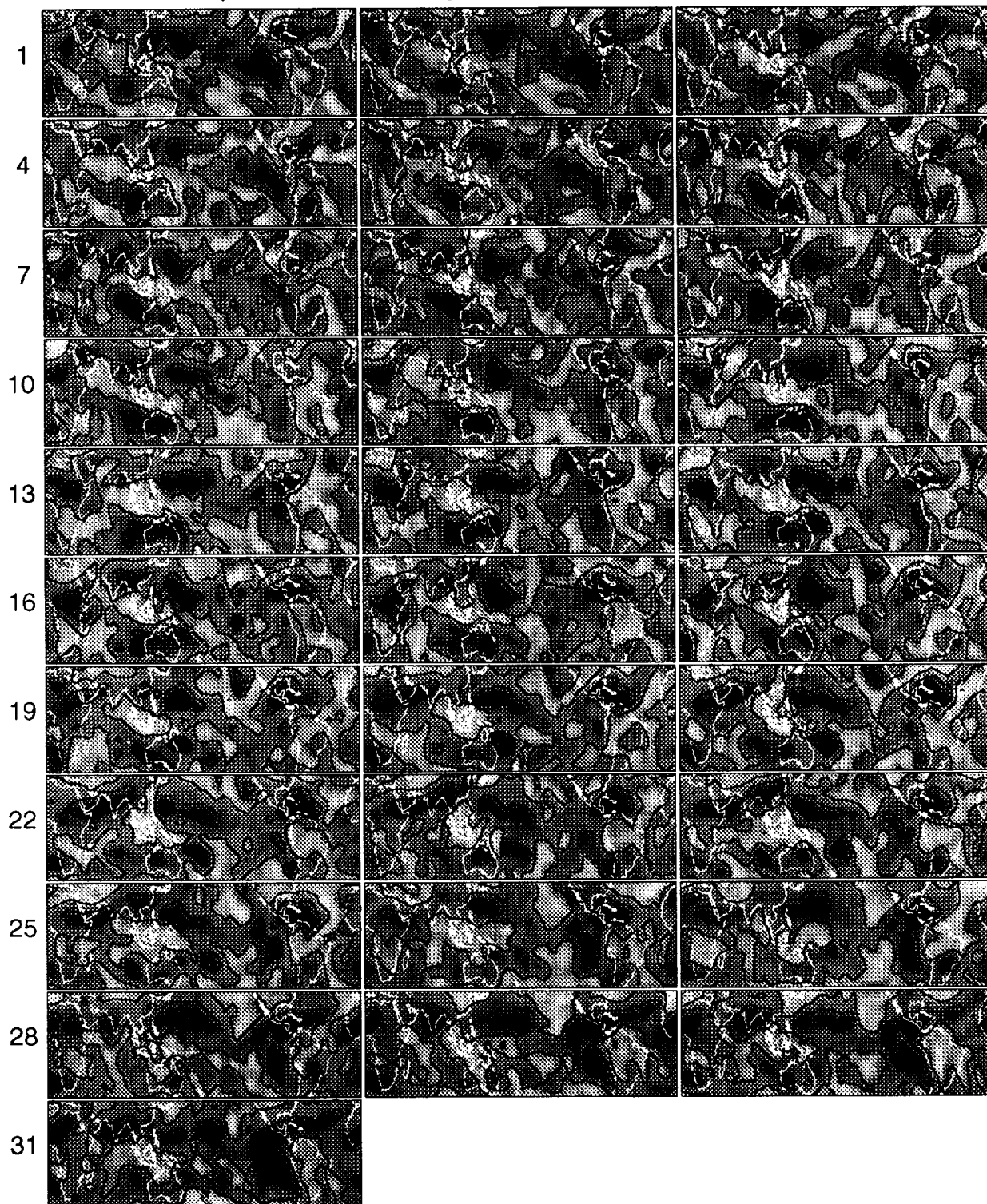


CLASS A-166 INFORMATIONALLY ONLY

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December 1985



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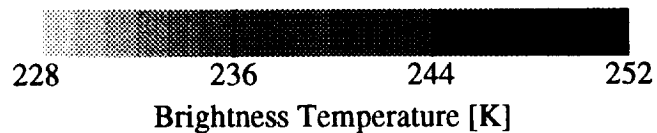
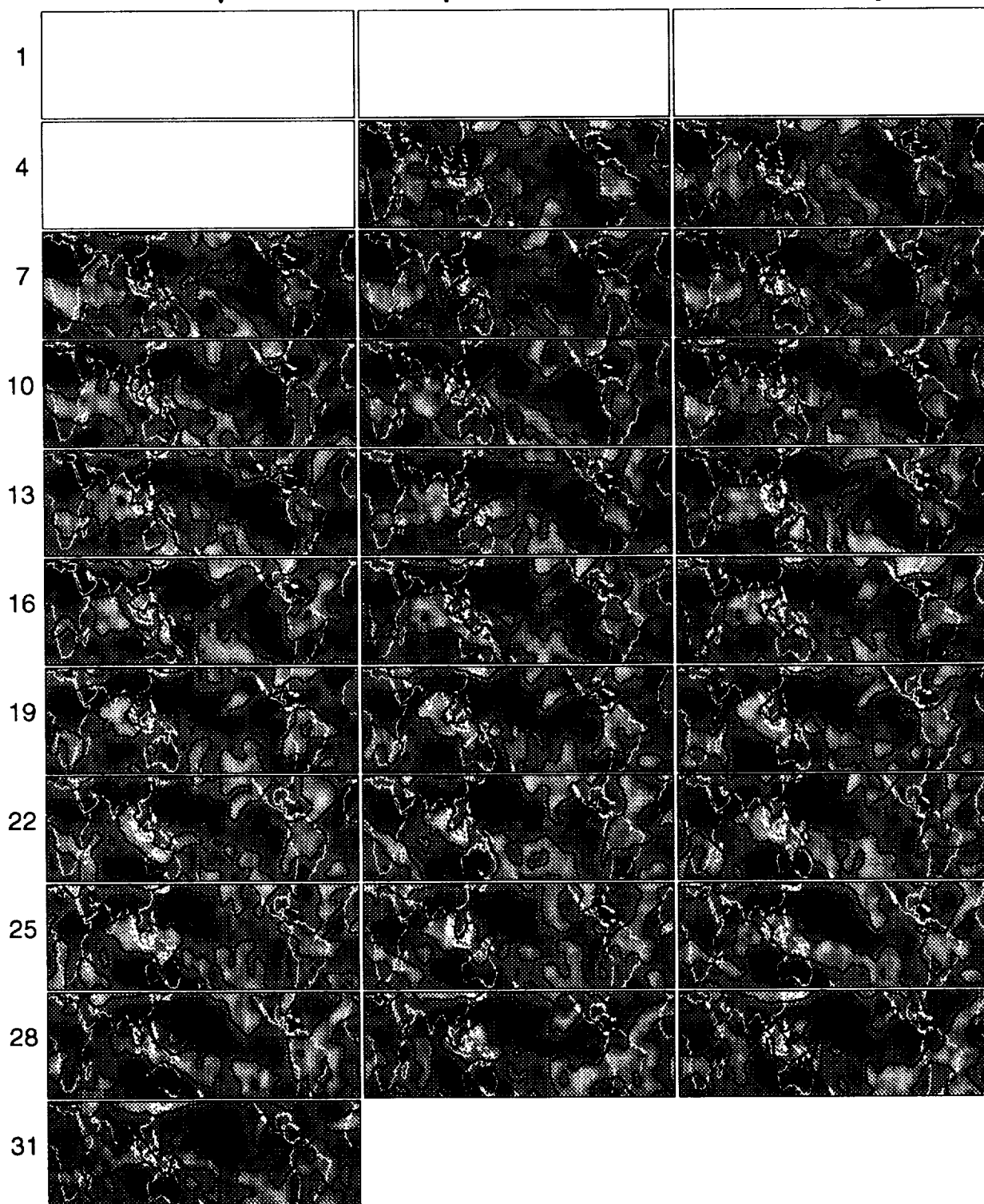
244

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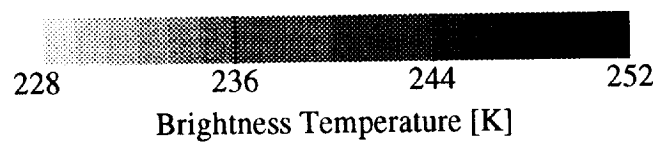
Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

January 1986

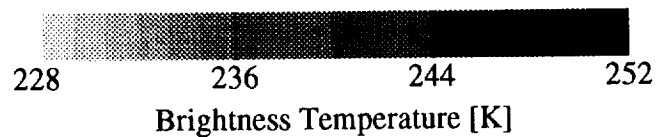
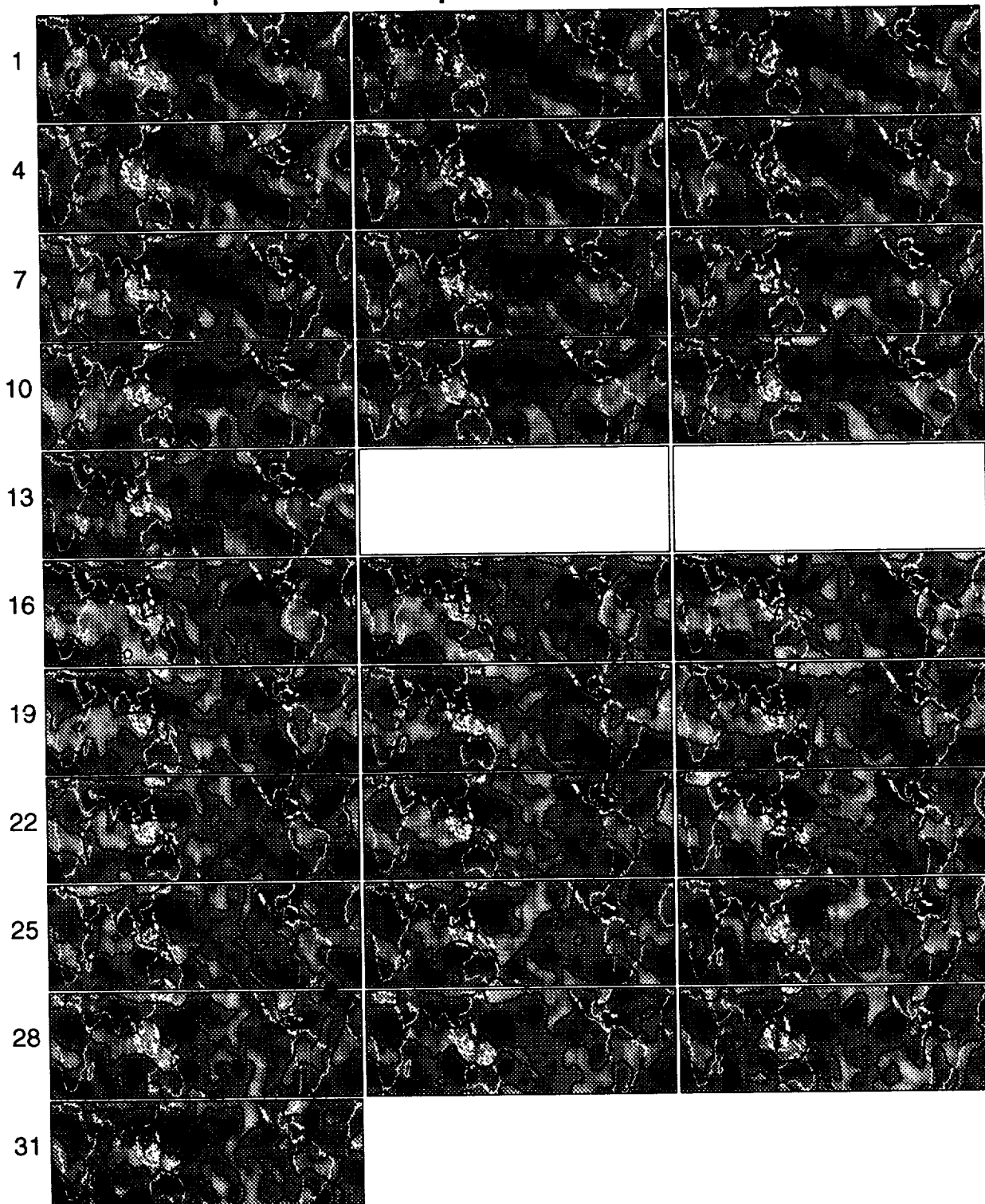


February 1986



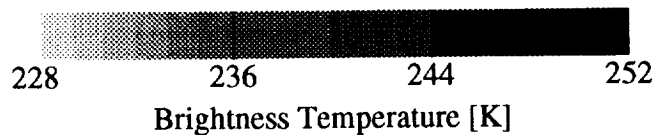
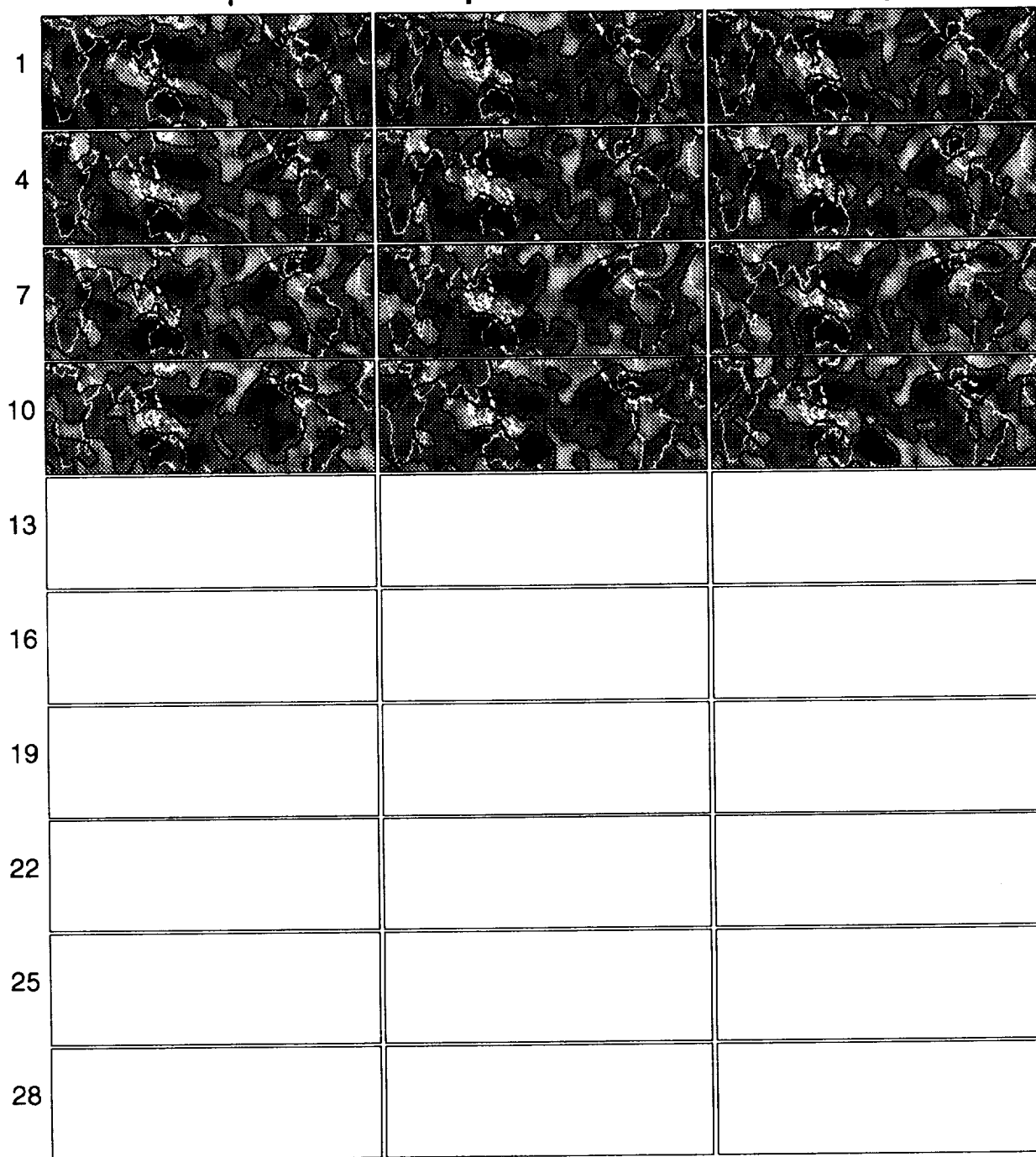
TOVS 6.5 μm Water Vapor Band

March 1986



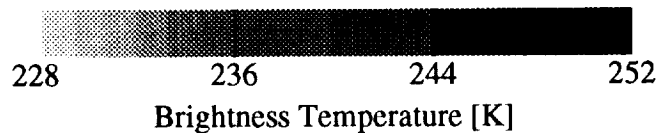
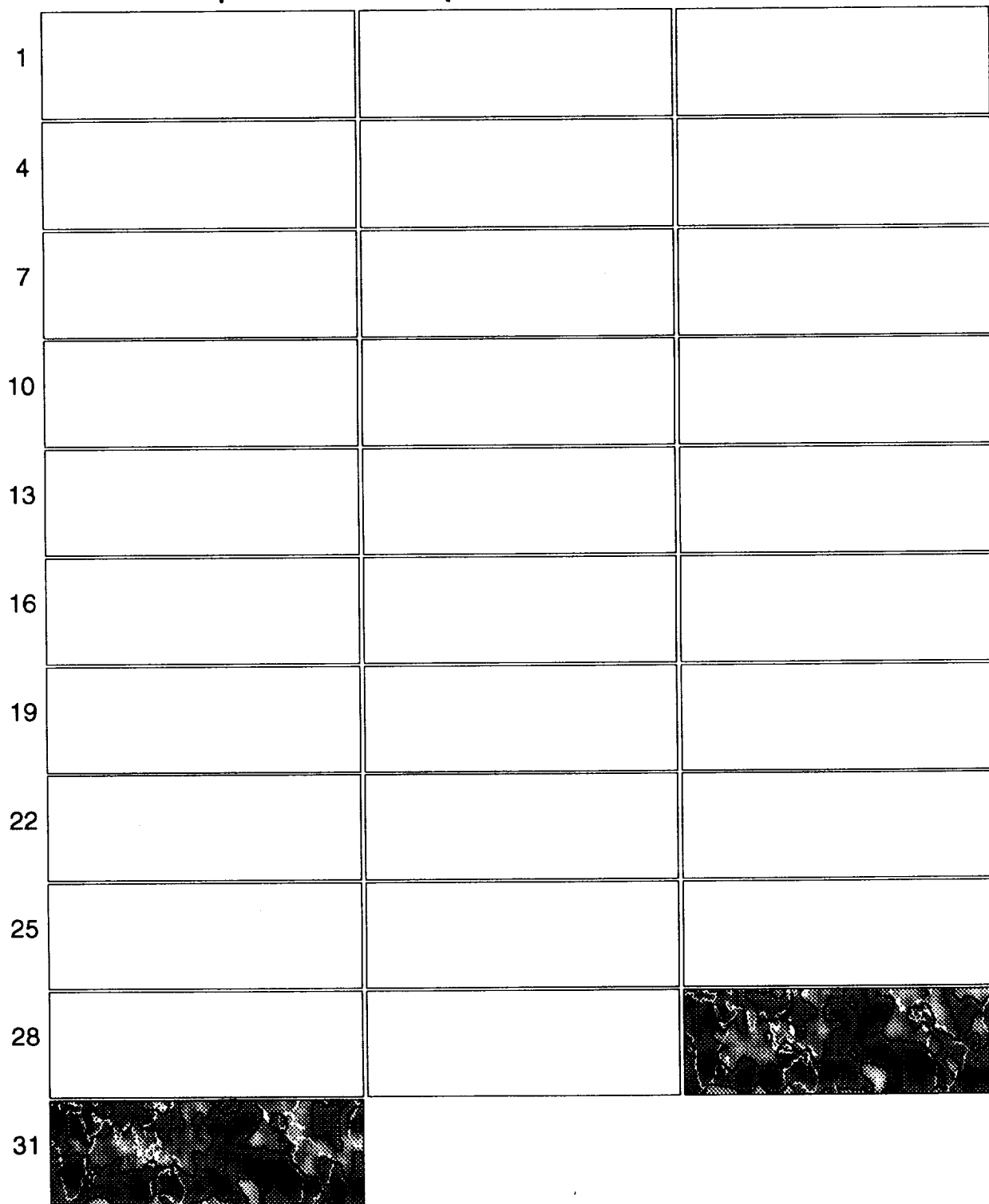
TOVS 6.5 μm Water Vapor Band

April 1986



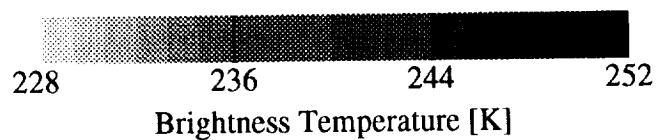
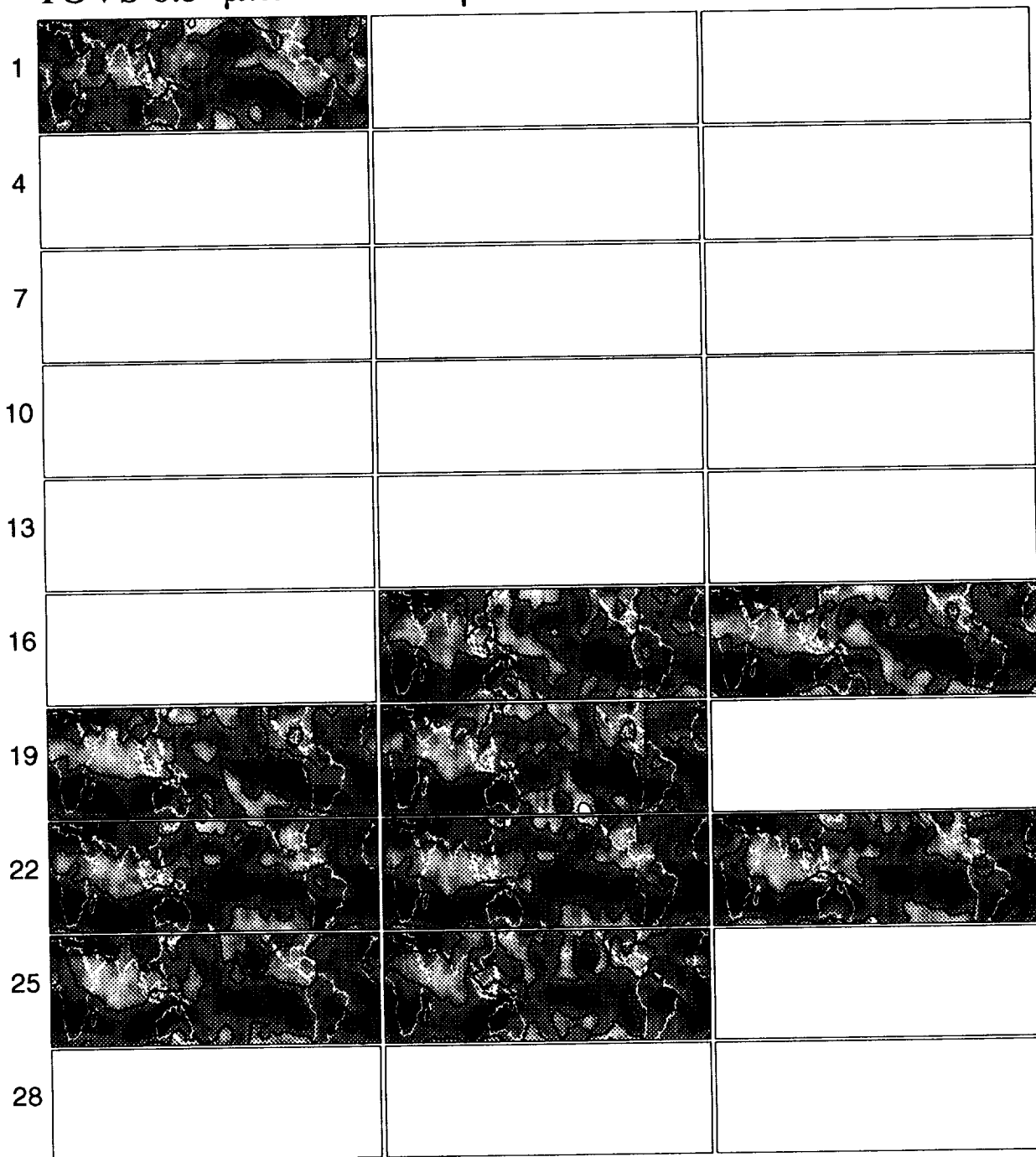
TOVS 6.5 μm Water Vapor Band

May 1986

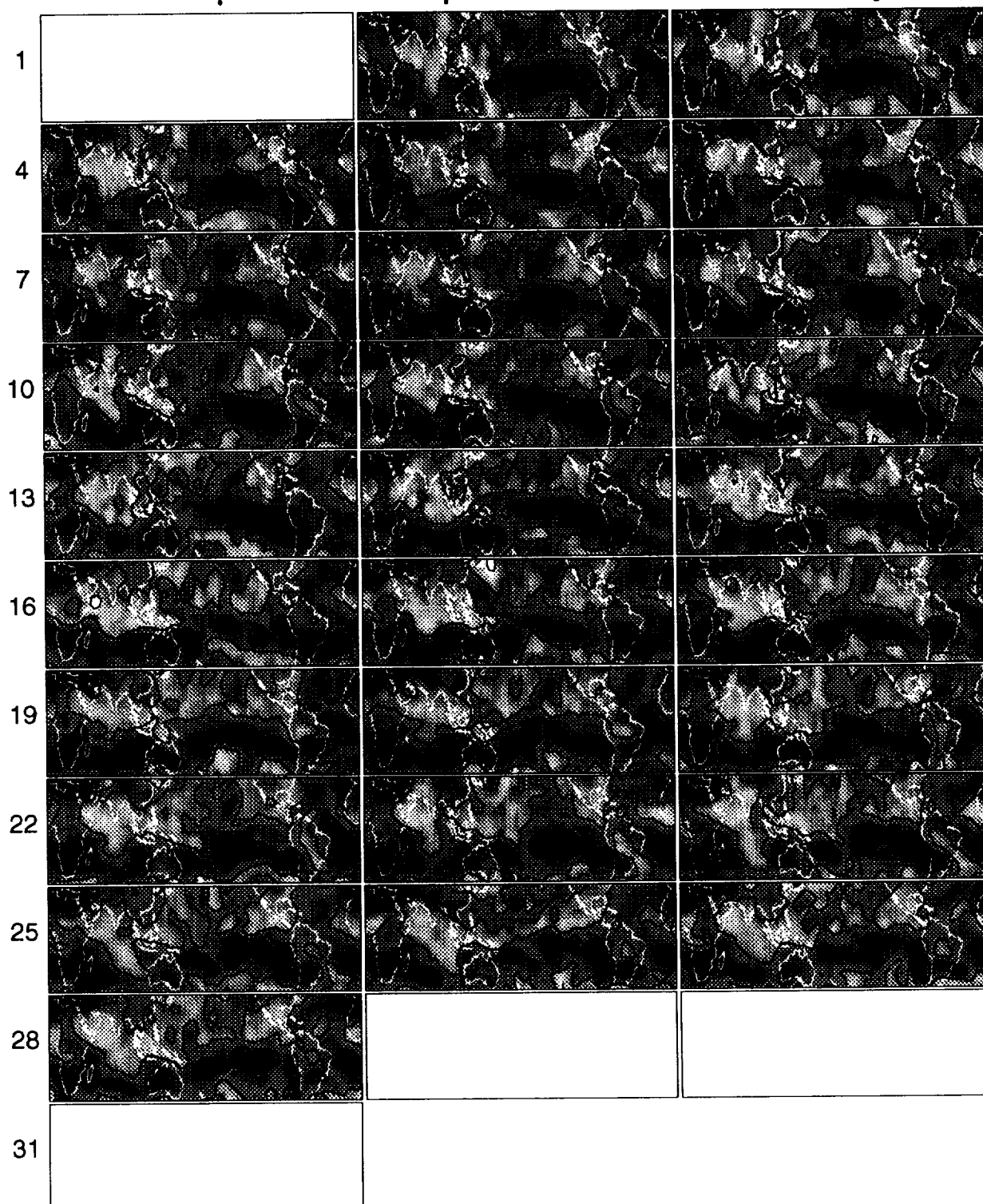


TOVS 6.5 μm Water Vapor Band

June 1986



July 1986



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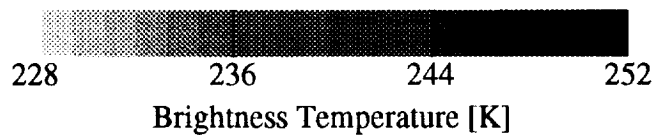
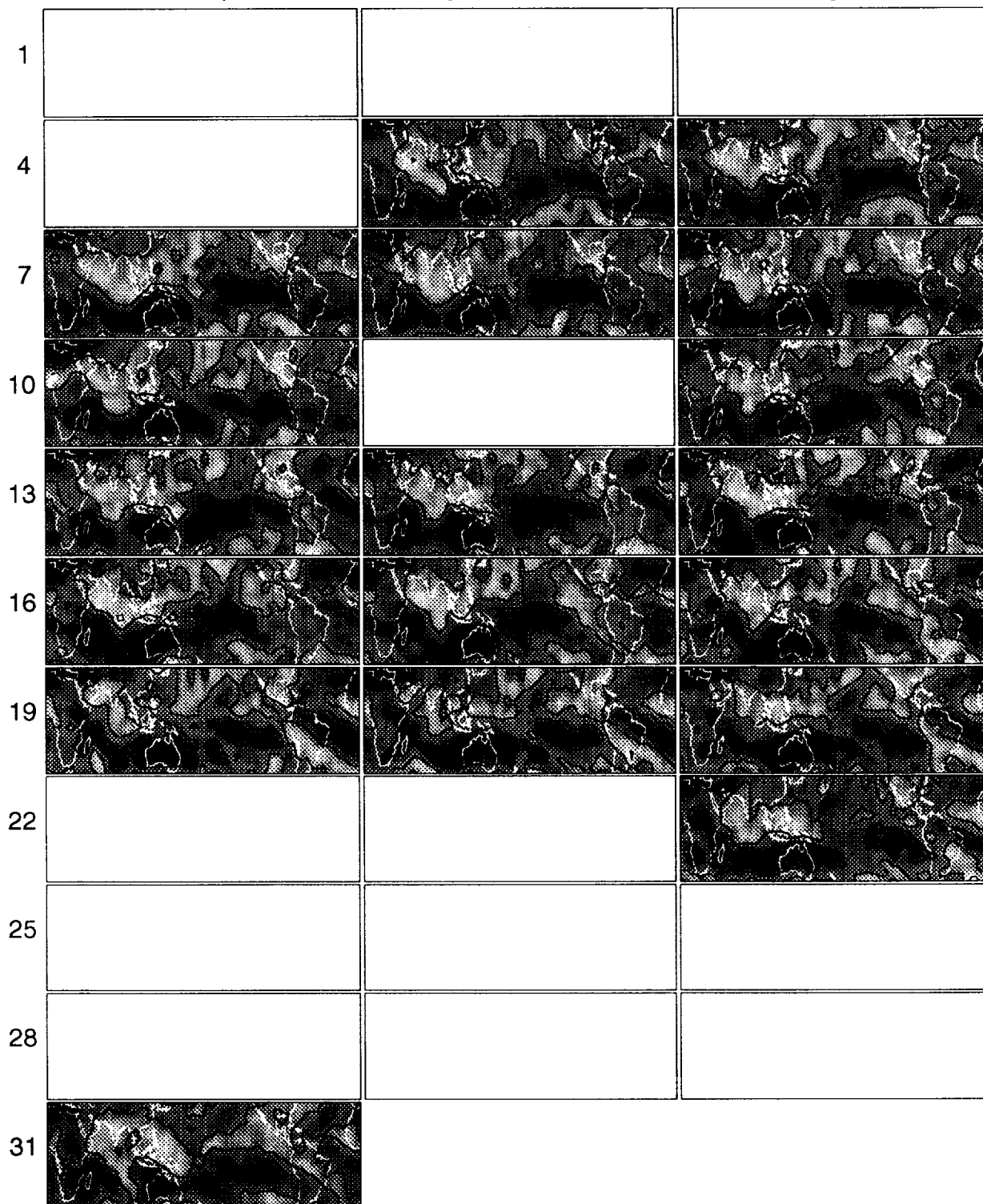
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Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

August 1986

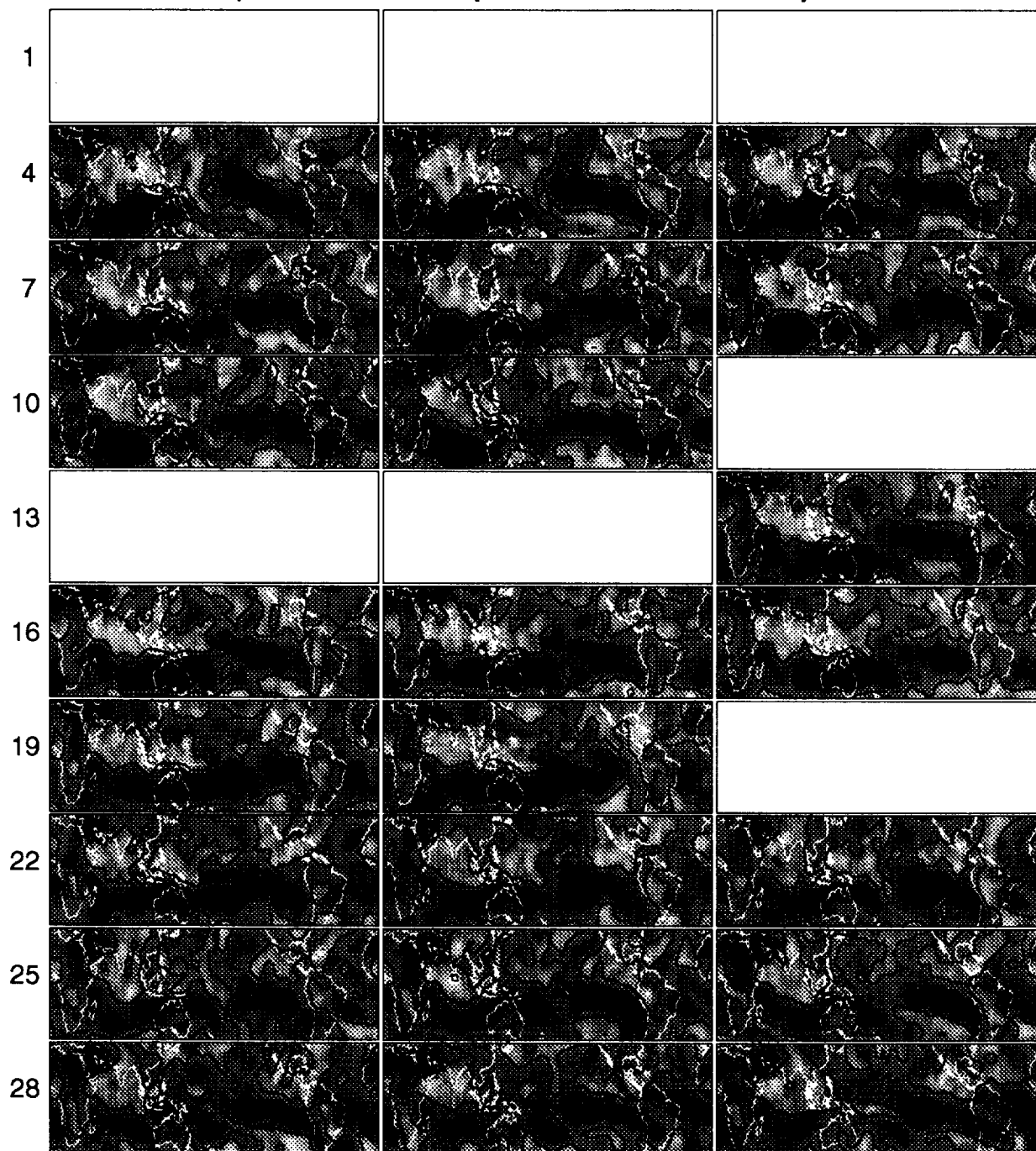


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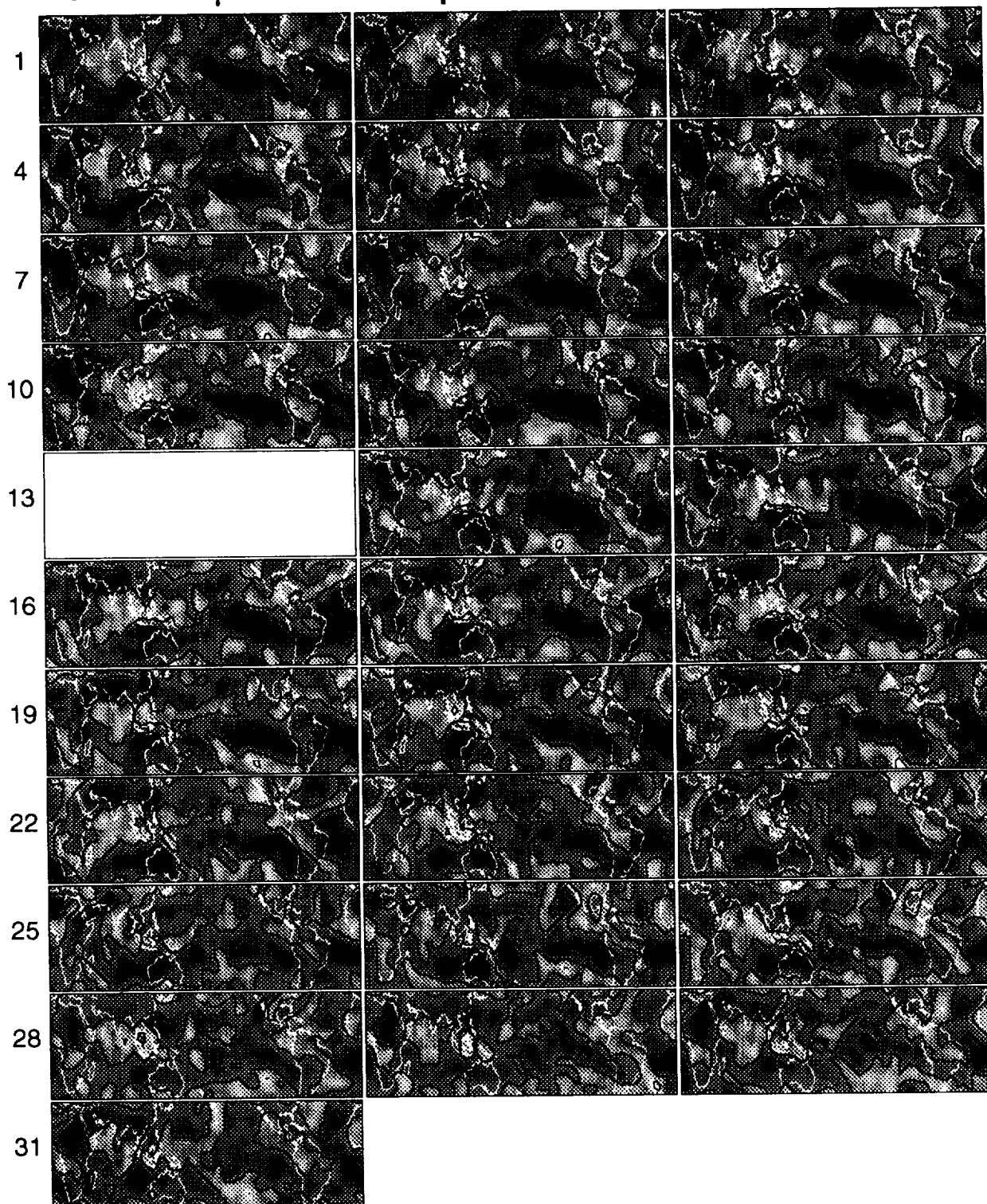
September 1986



Brightness Temperature [K]

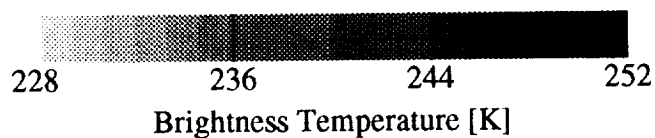
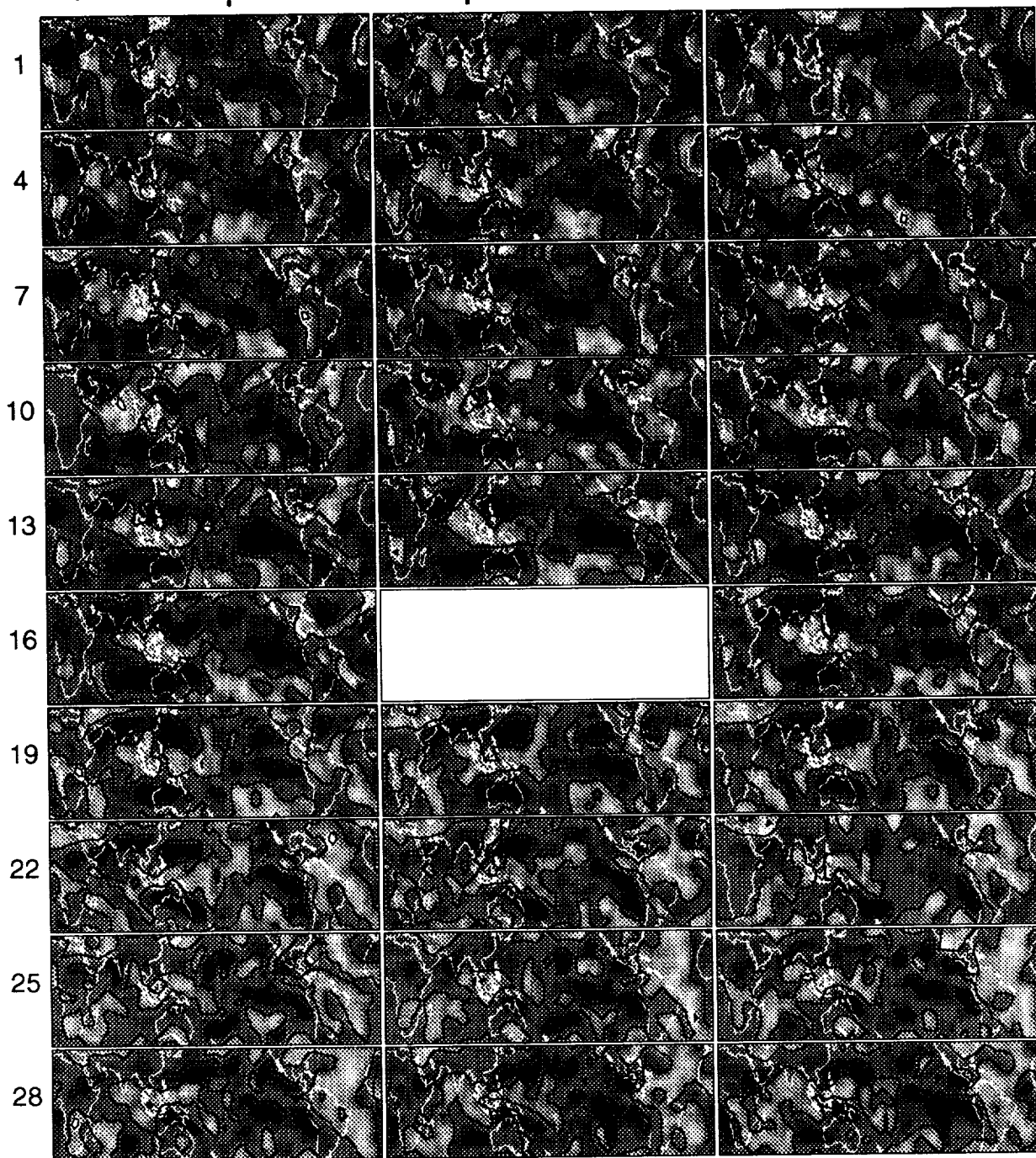
TOVS 6.5 μm Water Vapor Band

October 1986



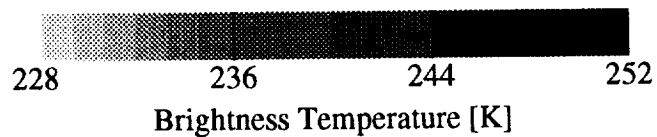
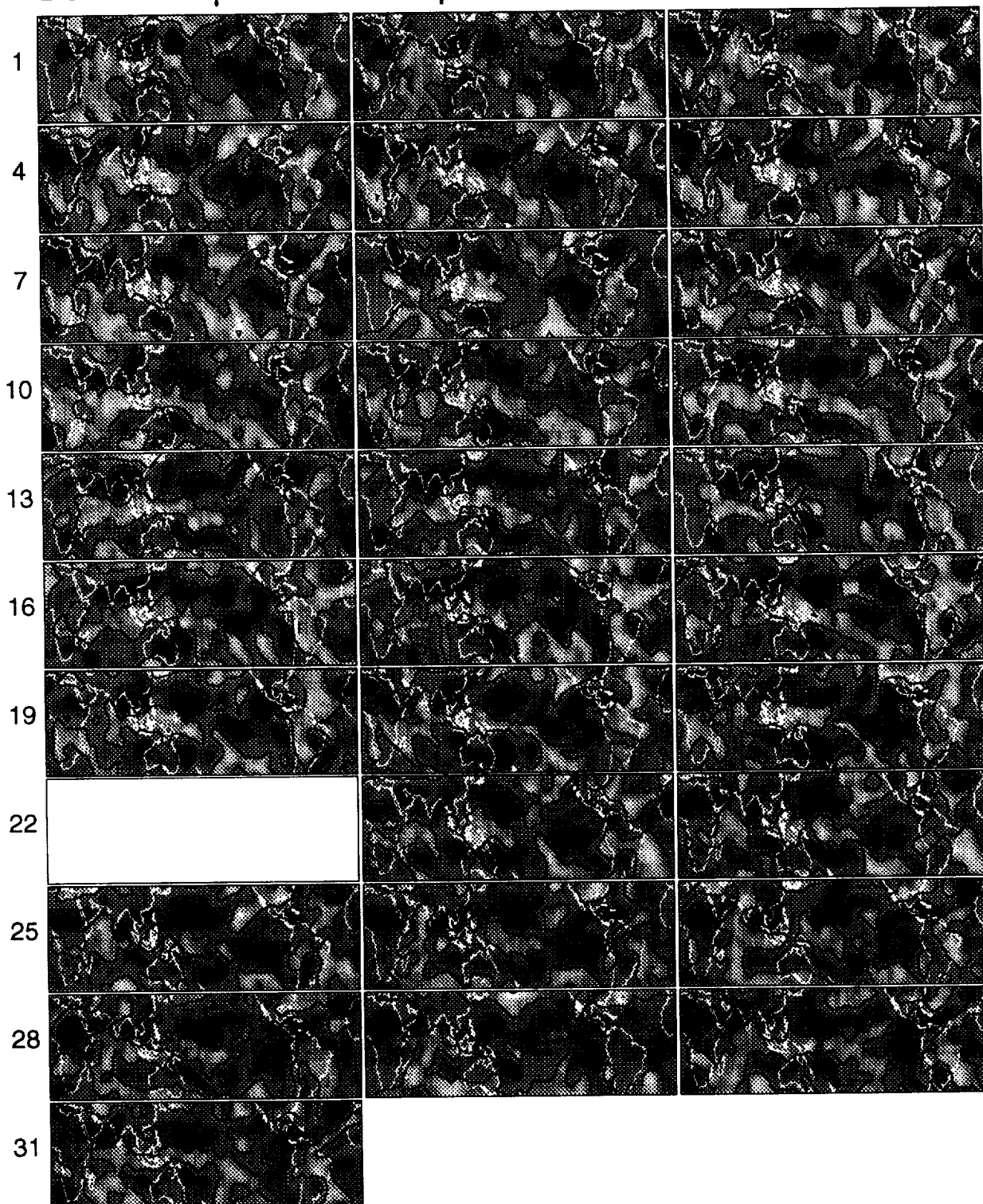
TOVS 6.5 μm Water Vapor Band

November 1986



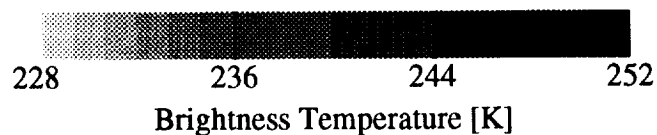
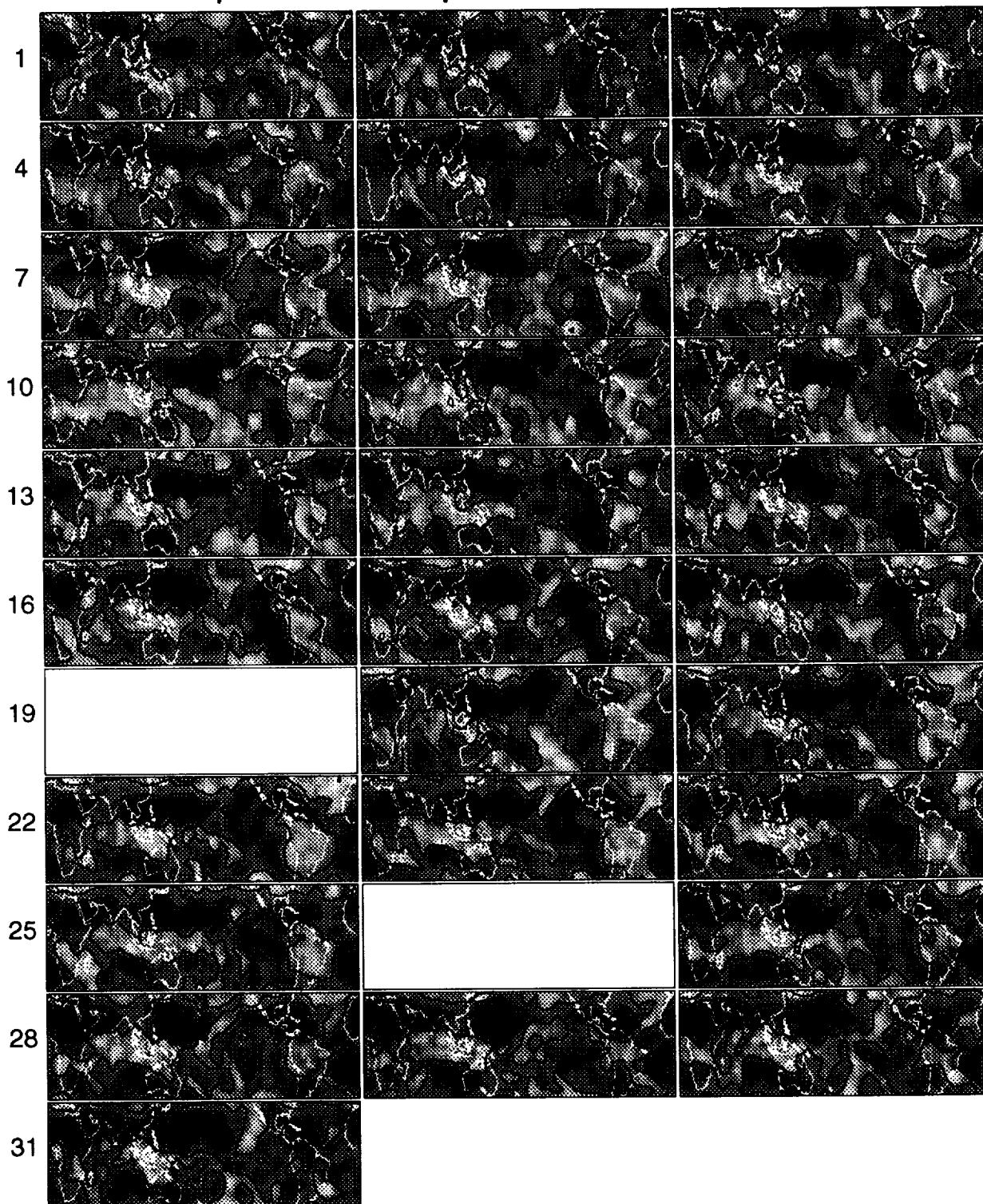
TOVS 6.5 μm Water Vapor Band

December 1986



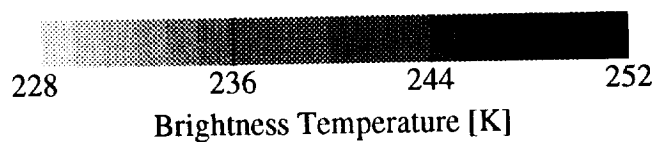
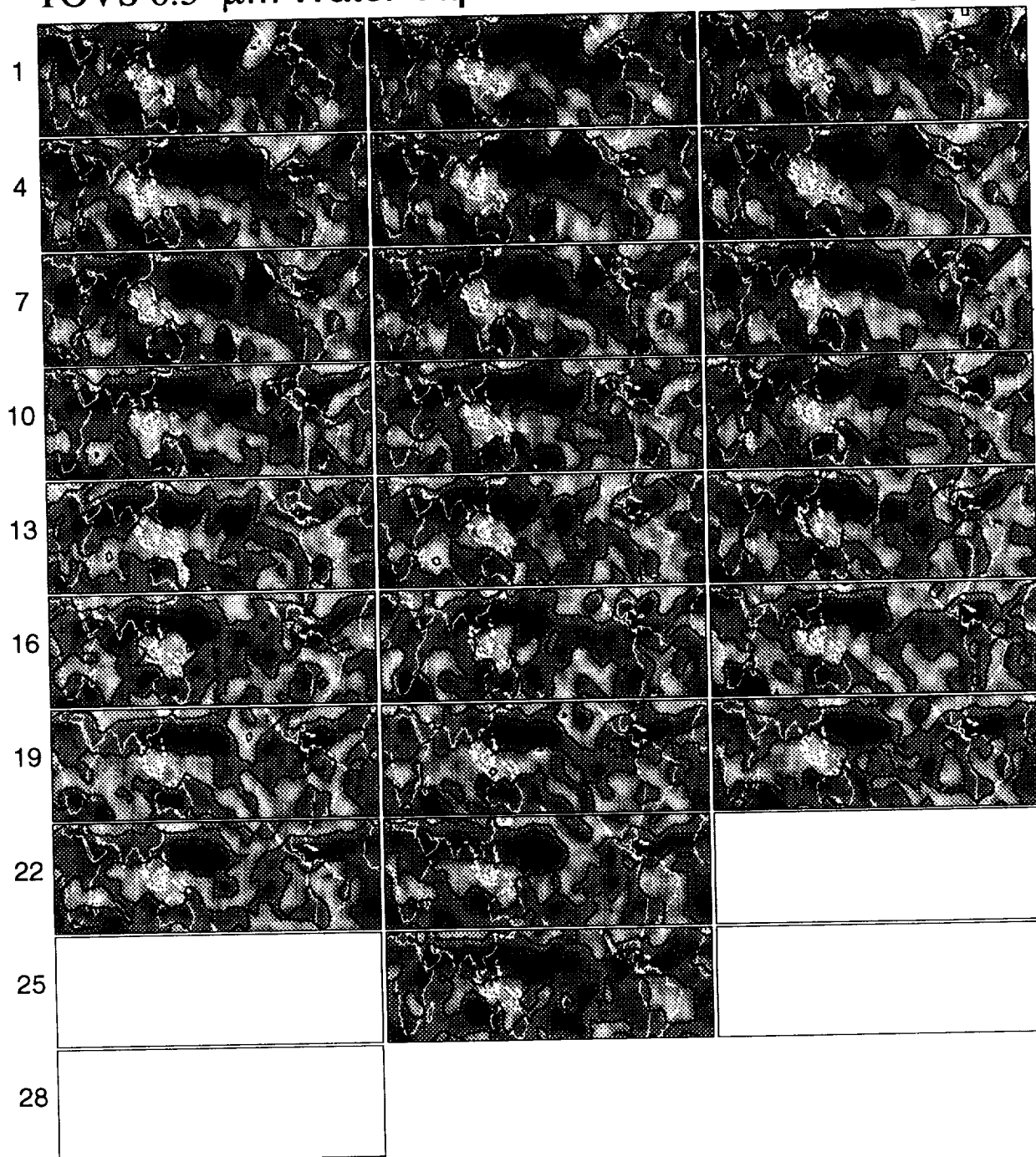
TOVS 6.5 μm Water Vapor Band

January 1987



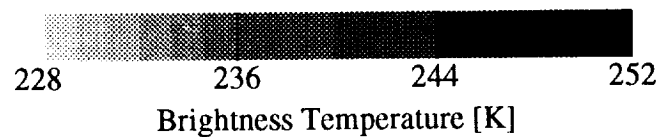
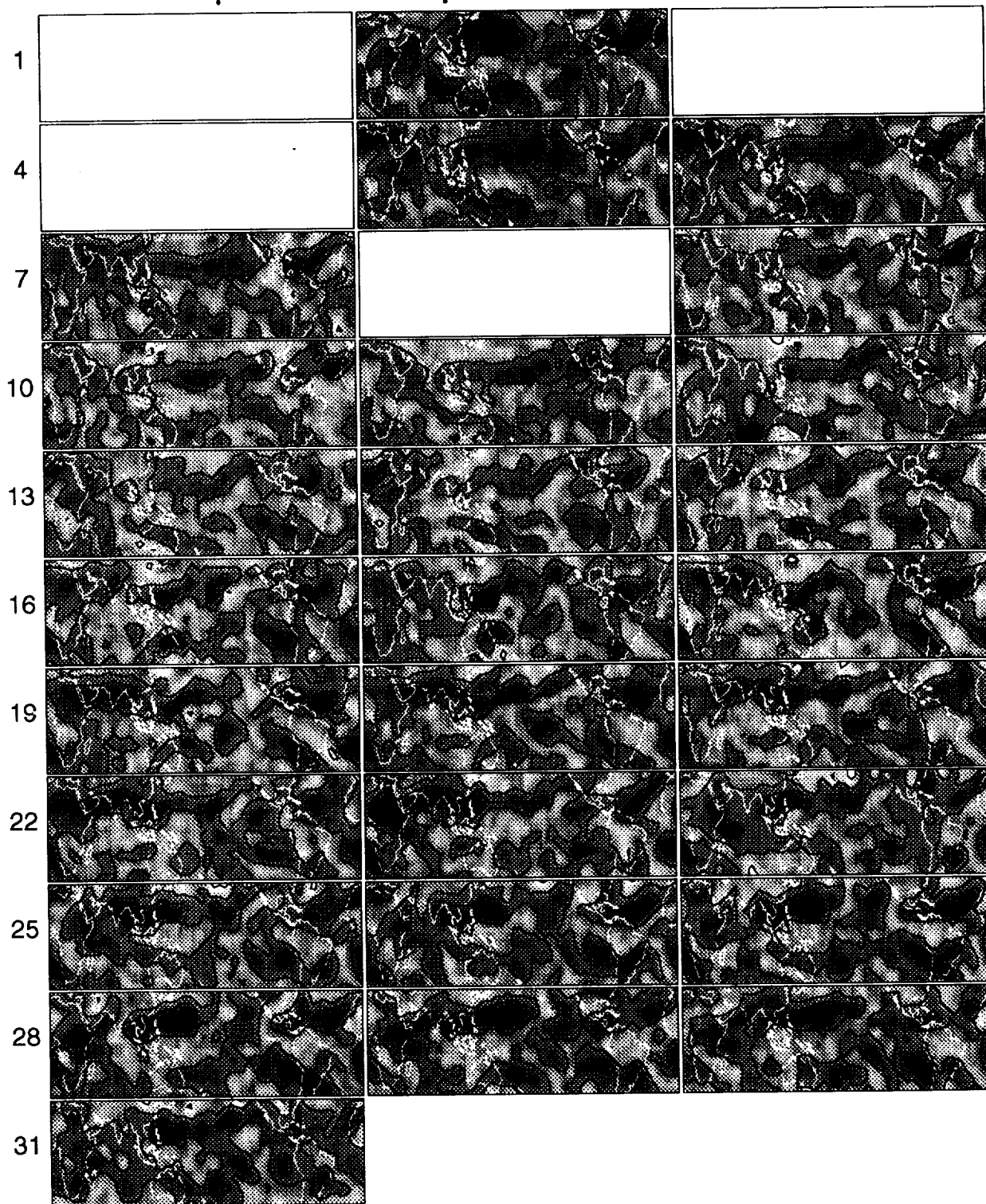
TOVS 6.5 μm Water Vapor Band

February 1987



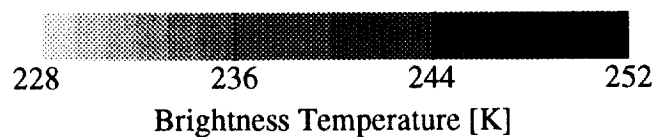
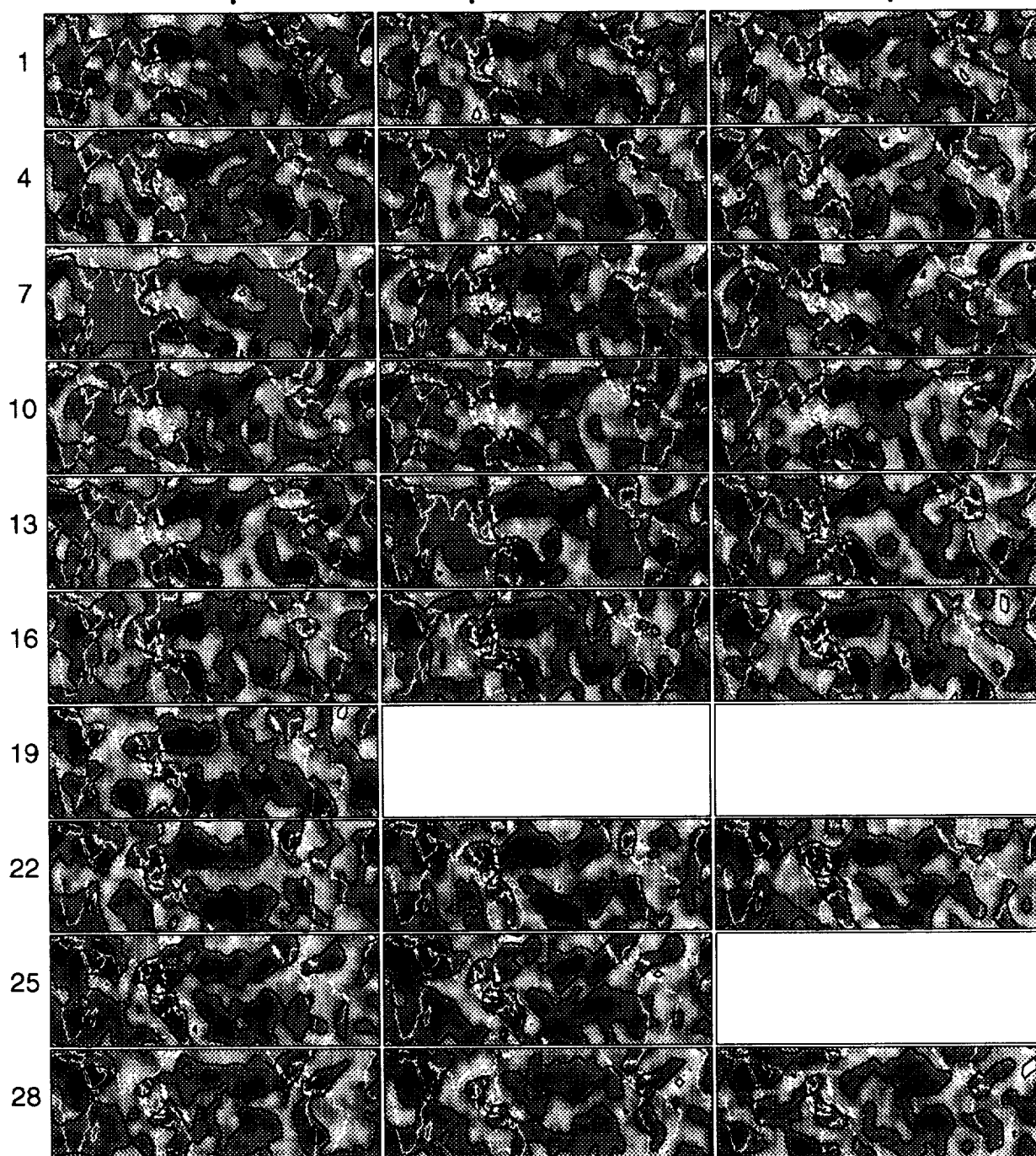
TOVS 6.5 μm Water Vapor Band

March 1987



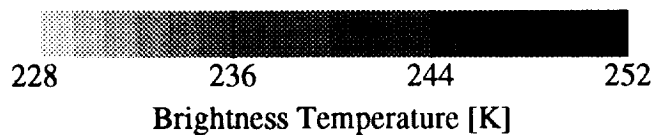
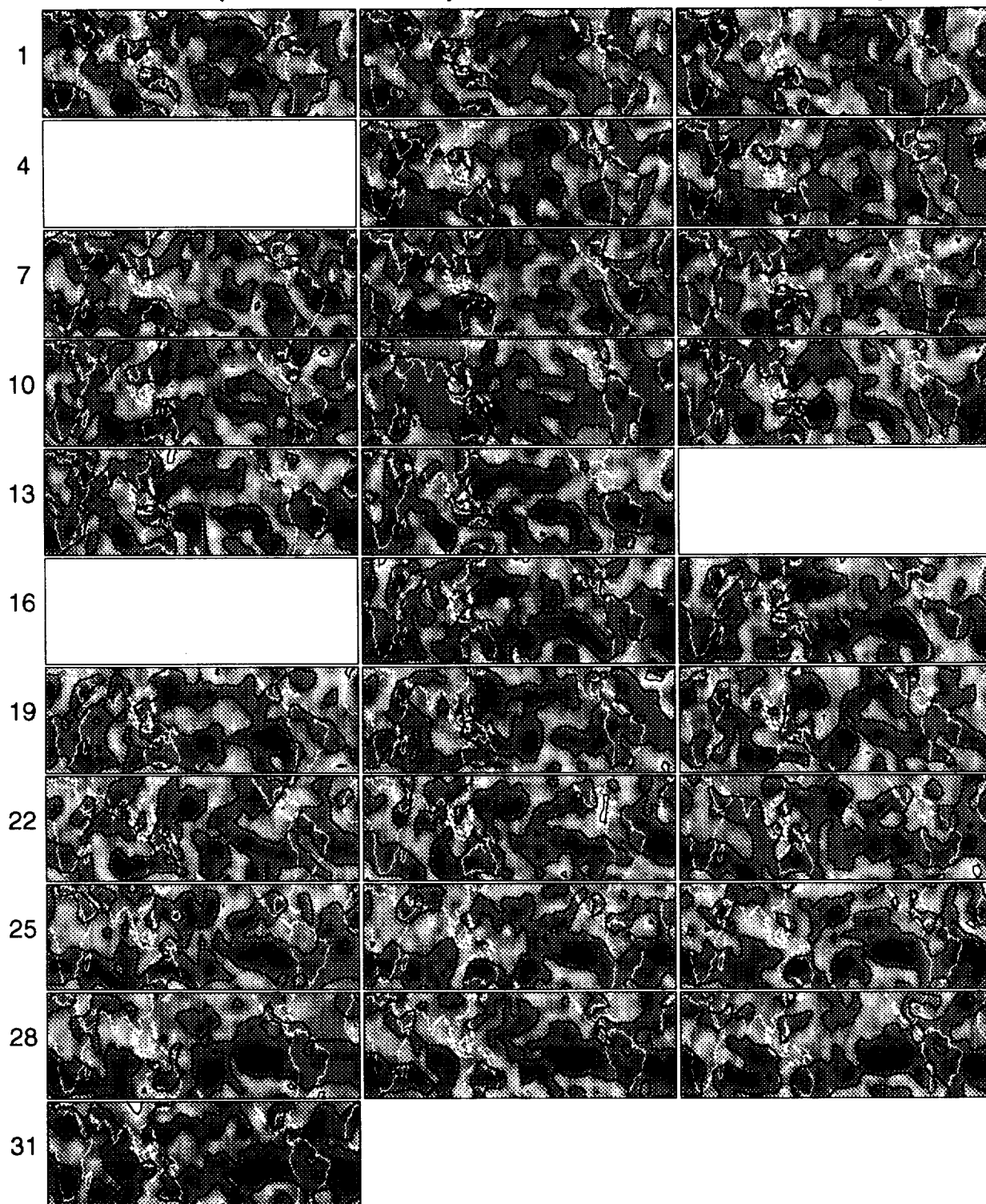
TOVS 6.5 μm Water Vapor Band

April 1987



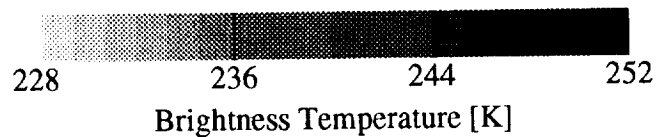
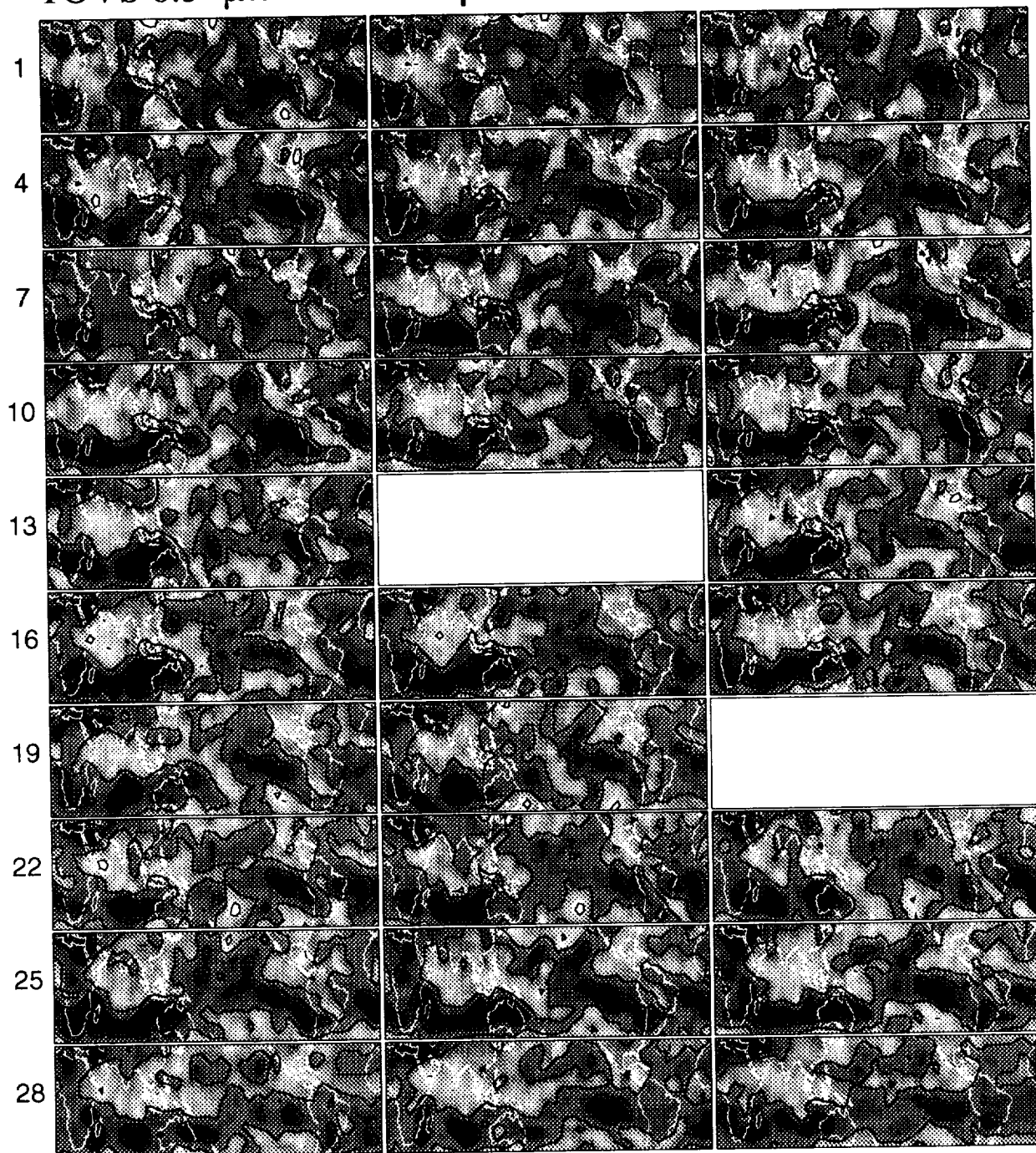
TOVS 6.5 μm Water Vapor Band

May 1987



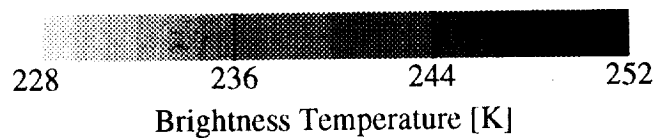
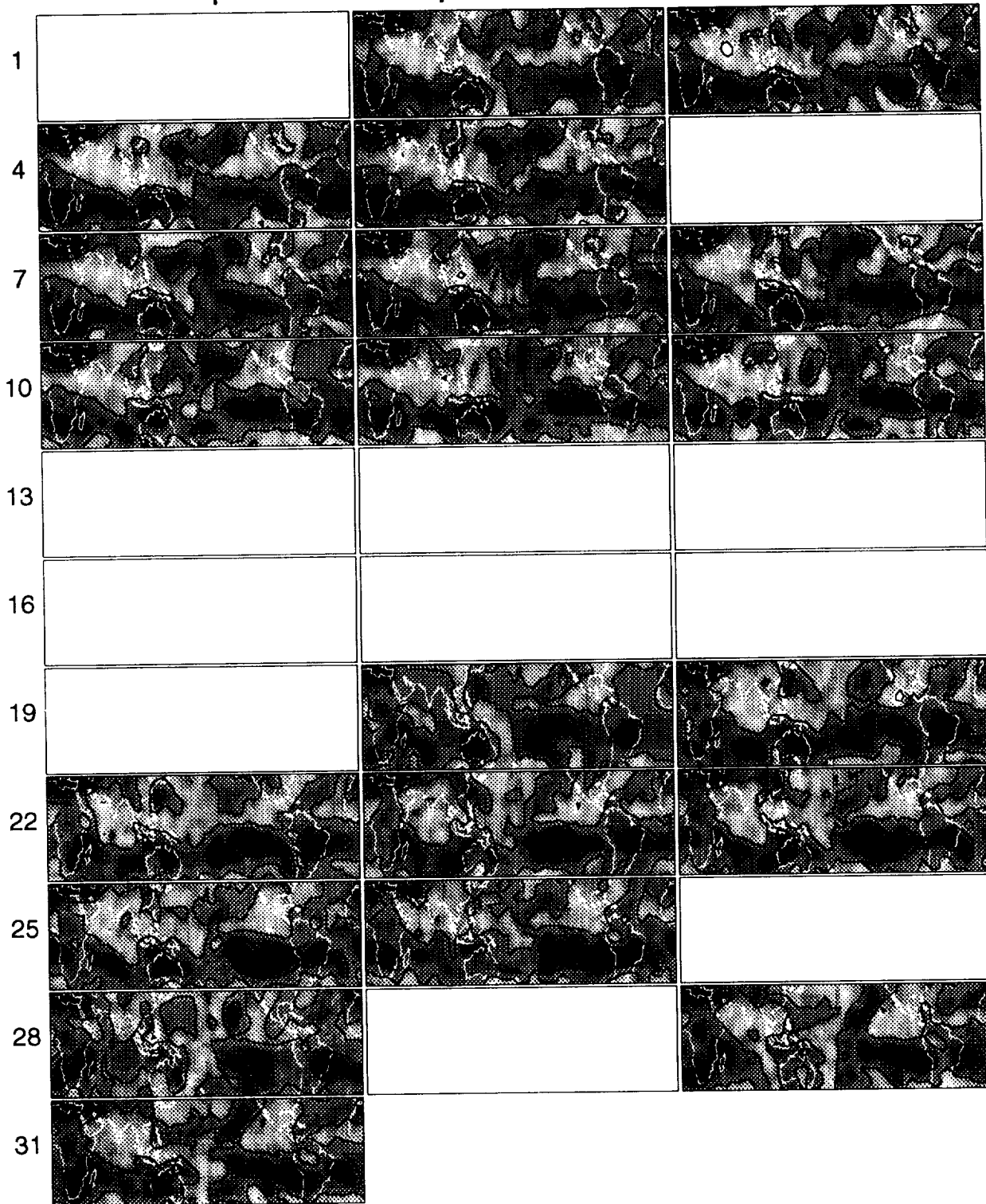
TOVS 6.5 μm Water Vapor Band

June 1987



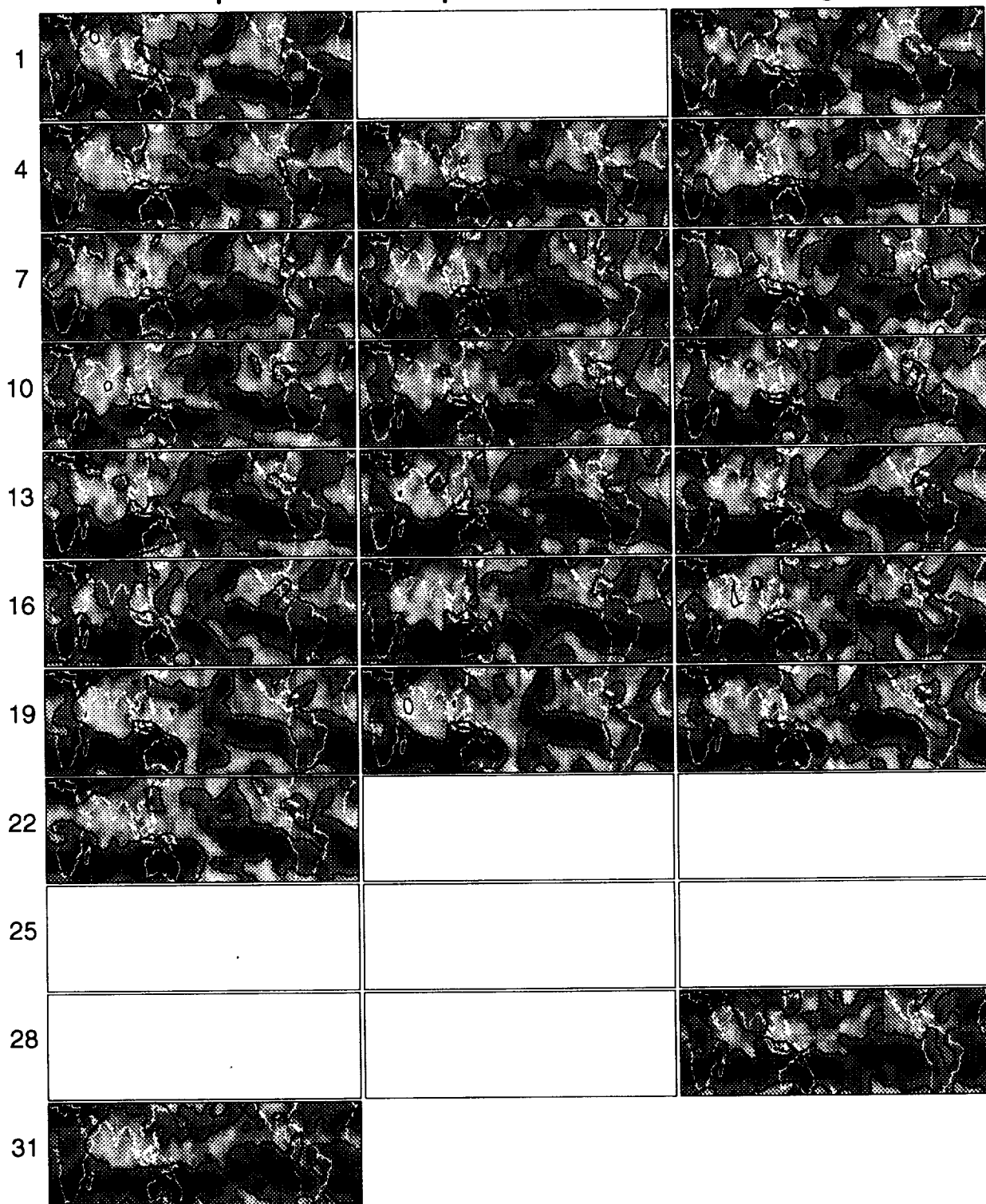
TOVS 6.5 μm Water Vapor Band

July 1987



TOVS 6.5 μm Water Vapor Band

August 1987



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Brightness Temperature [K]

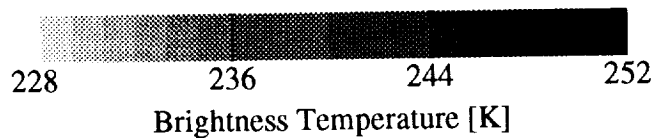
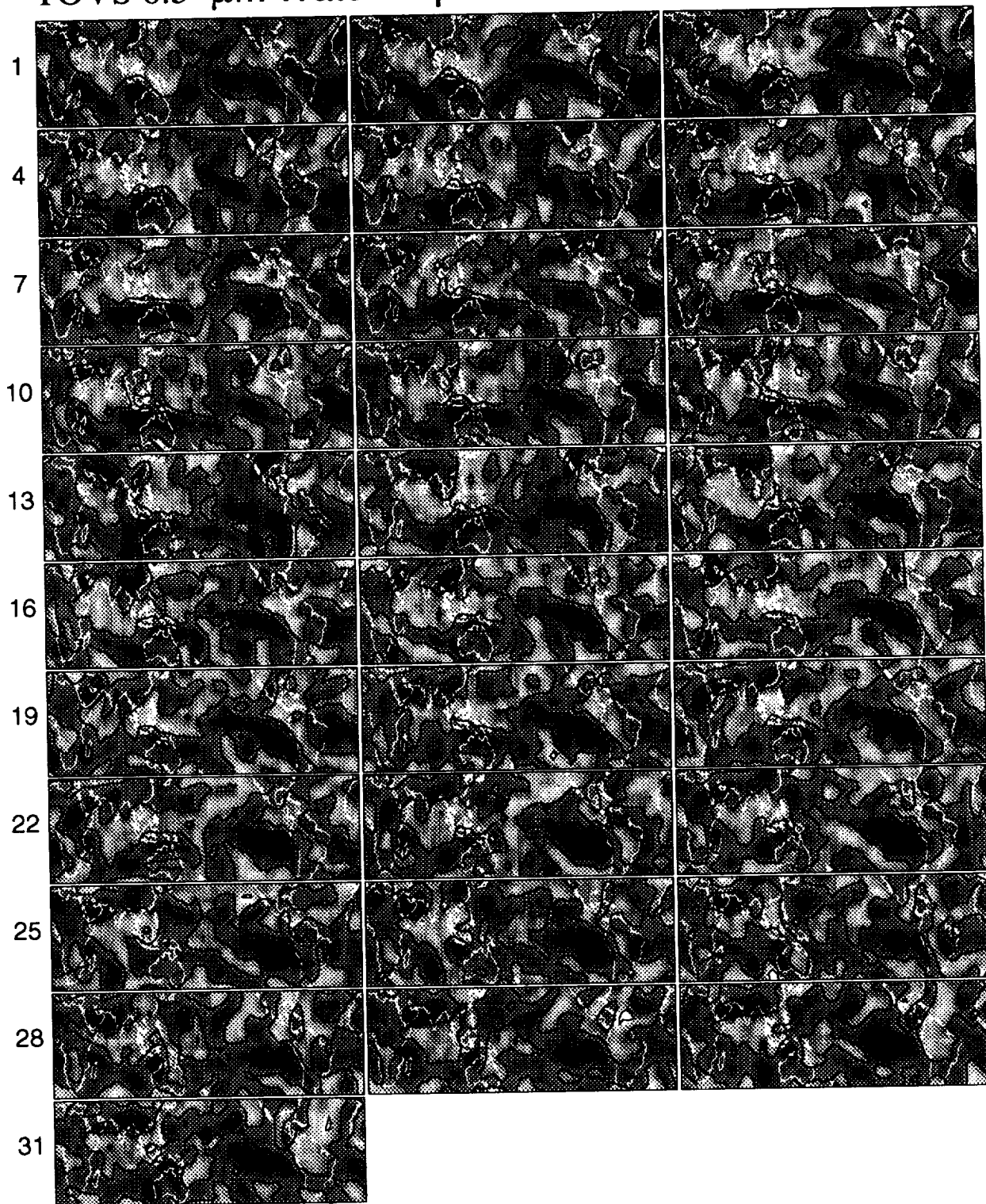
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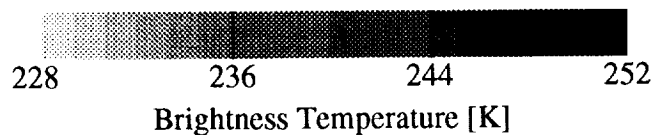
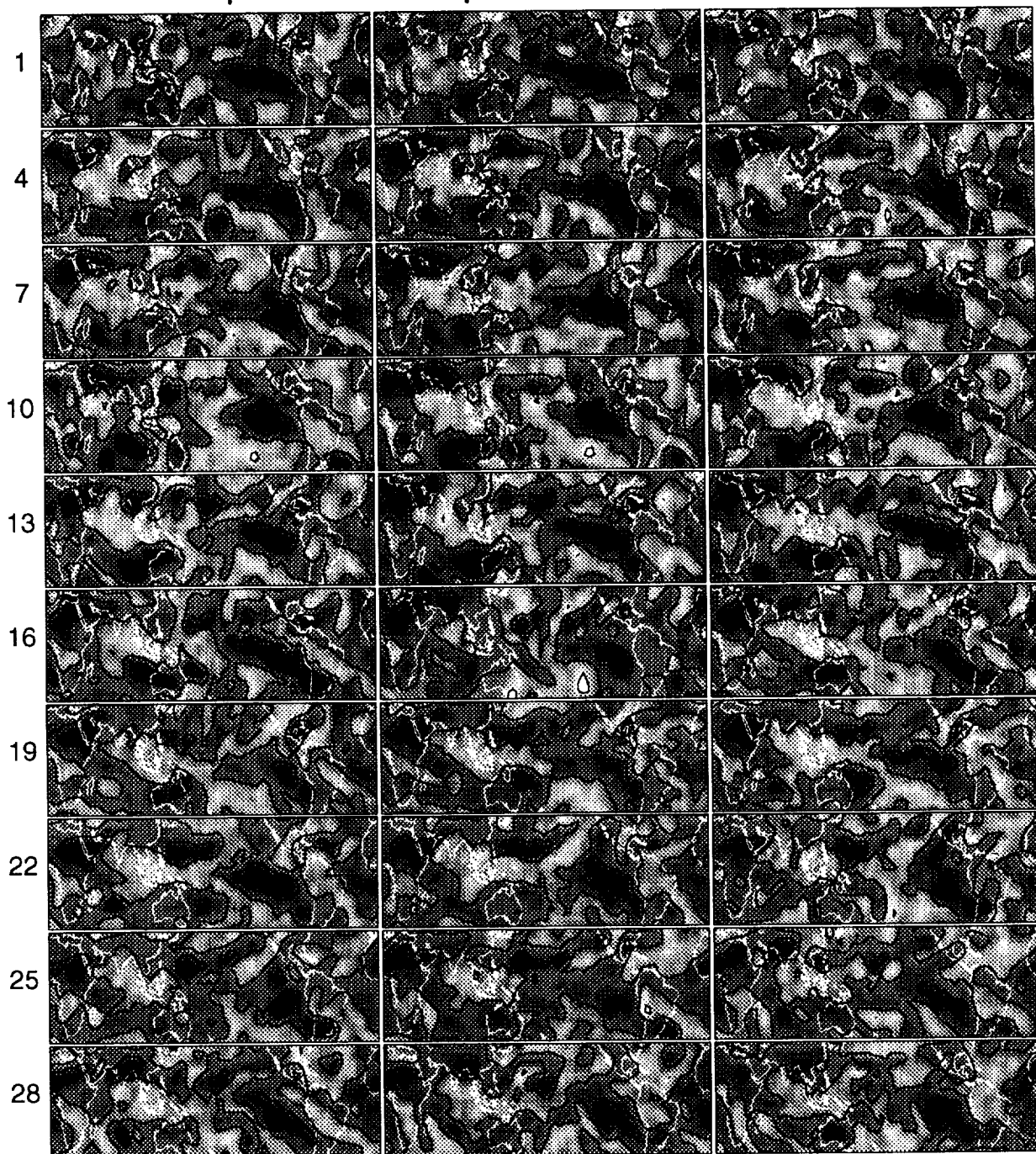
TOVS 6.5 μm Water Vapor Band

October 1987



TOVS 6.5 μm Water Vapor Band

November 1987



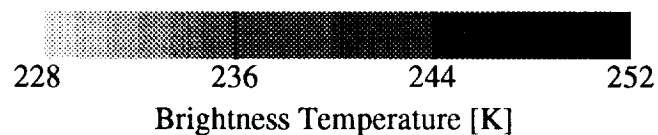
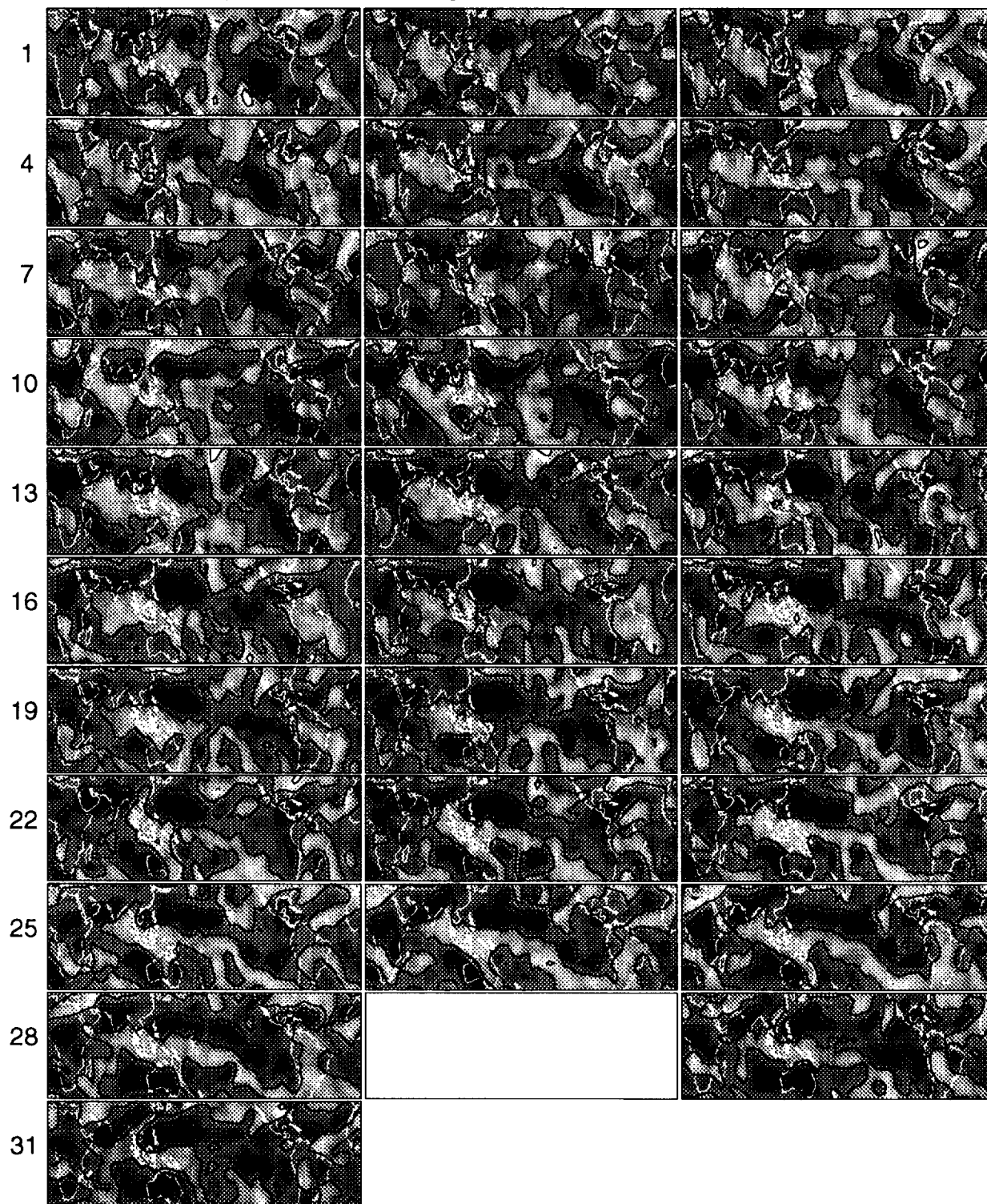
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TOVS 6.5 μm Water Vapor Band

December 1987



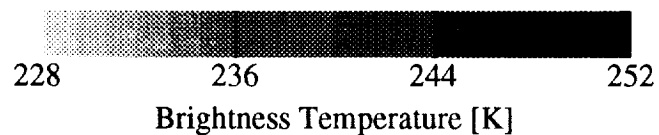
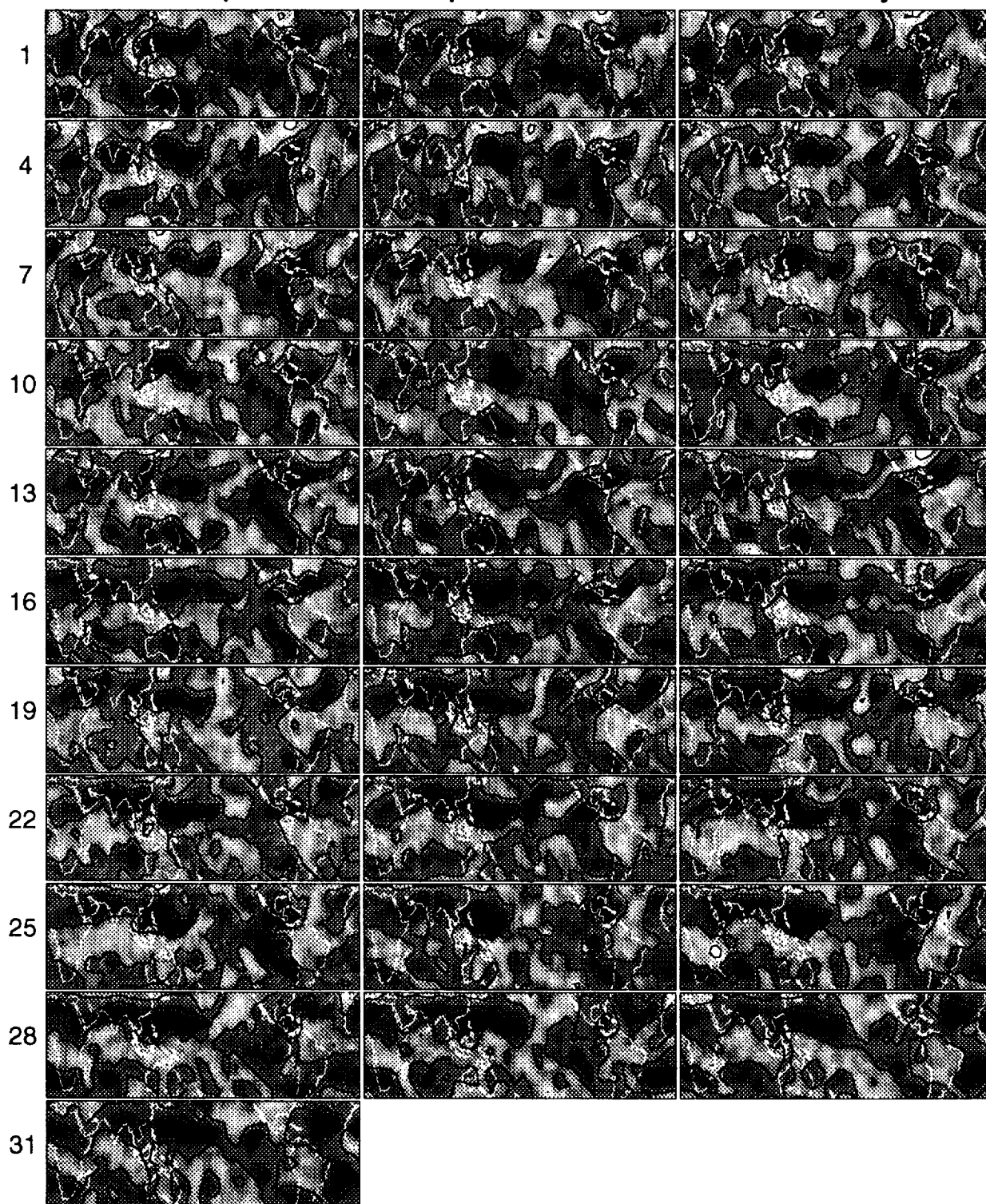
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A-217

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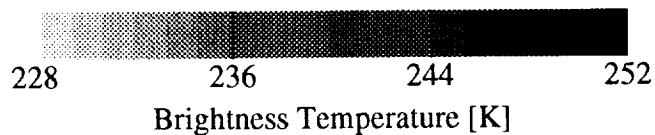
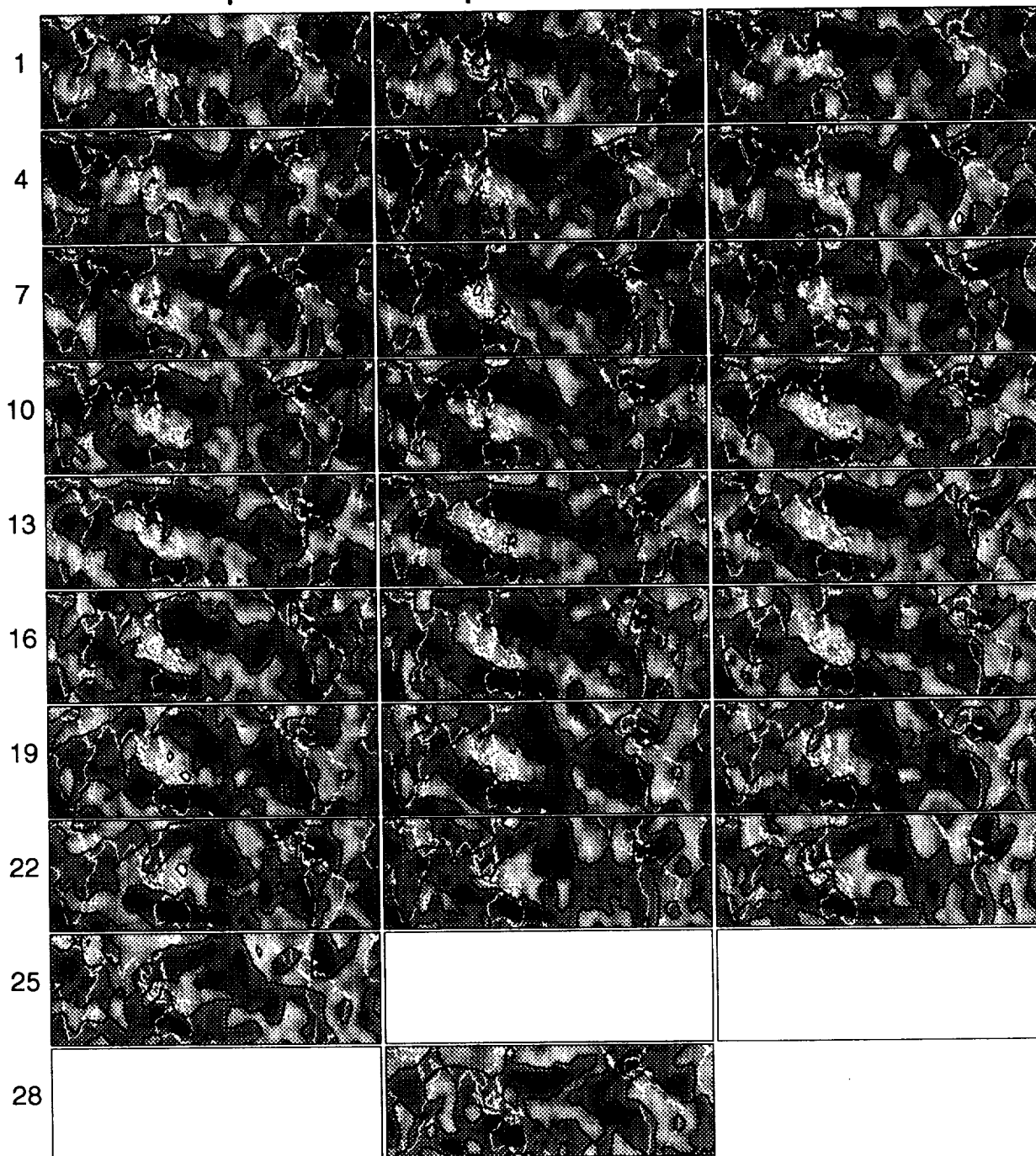
TOVS 6.5 μm Water Vapor Band

January 1988



TOVS 6.5 μm Water Vapor Band

February 1988



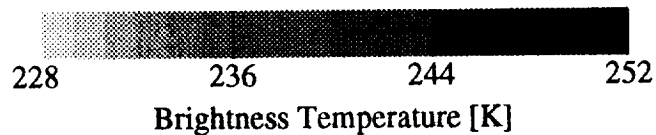
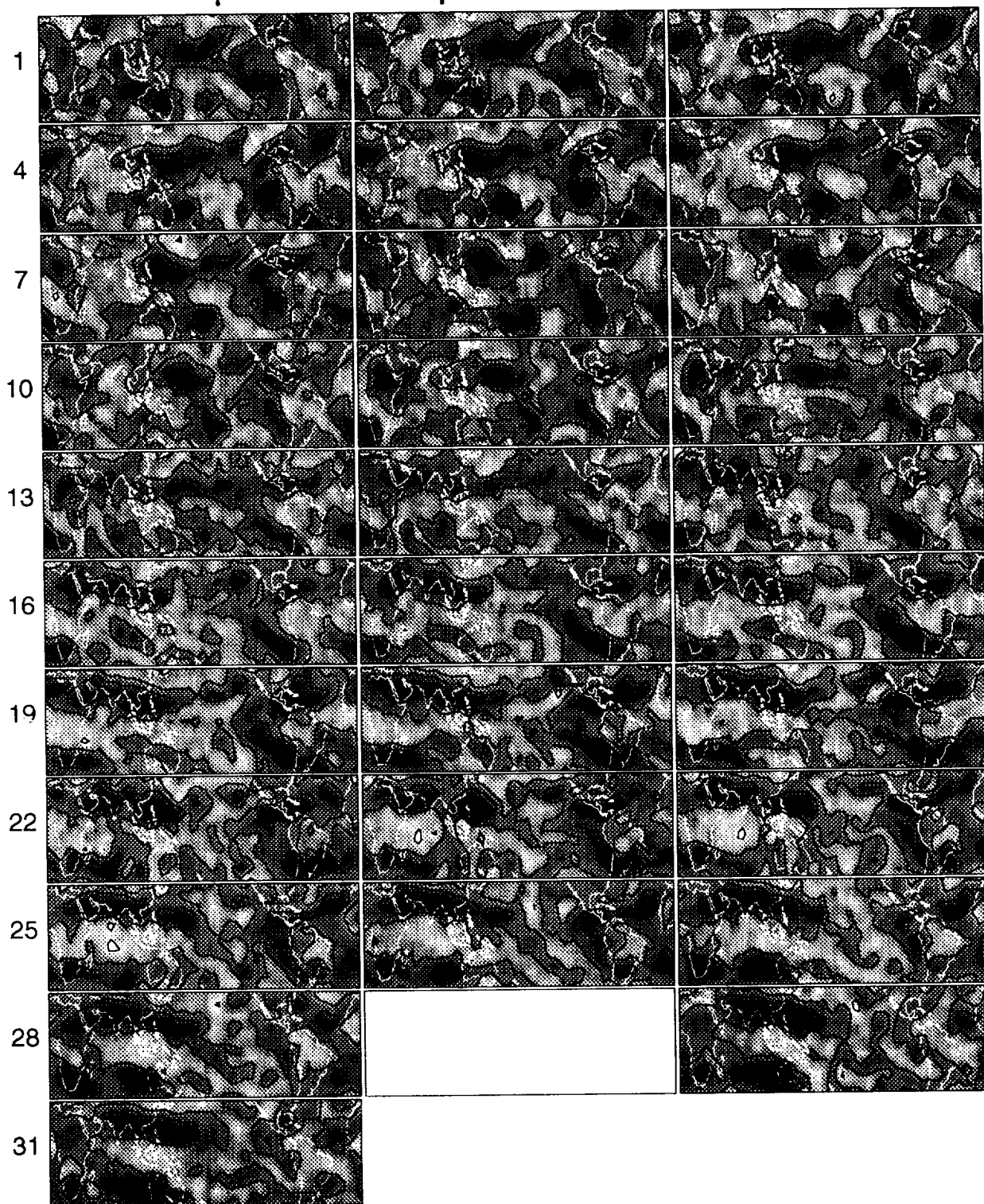
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TOVS 6.5 μm Water Vapor Band

March 1988



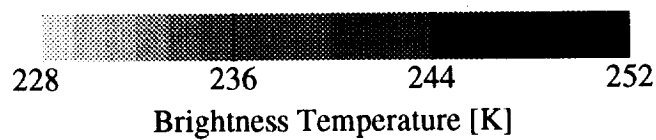
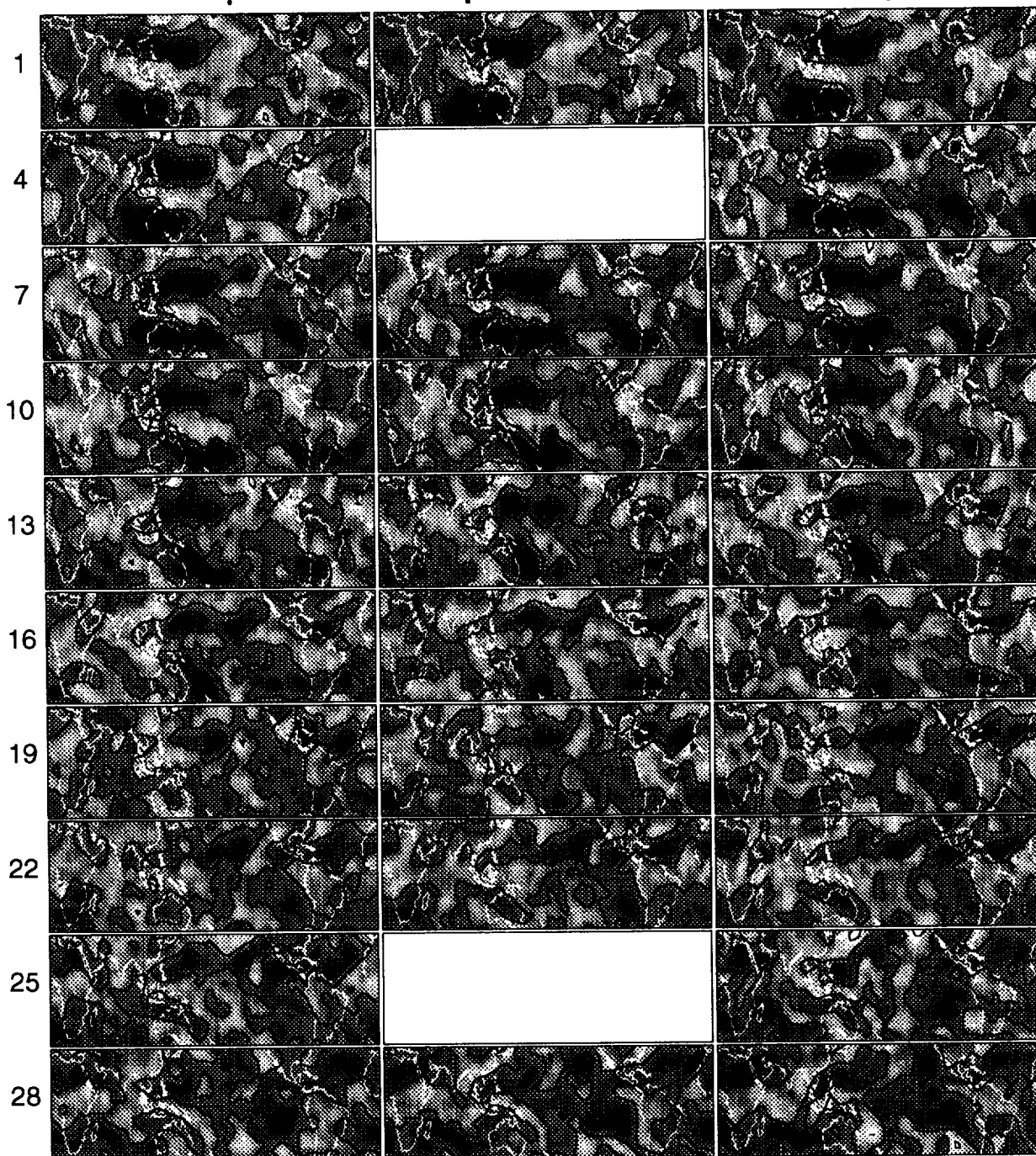
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TOVS 6.5 μm Water Vapor Band

April 1988



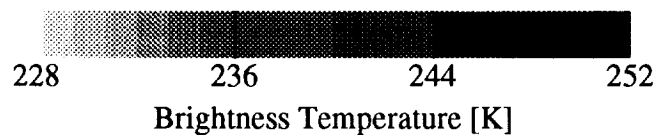
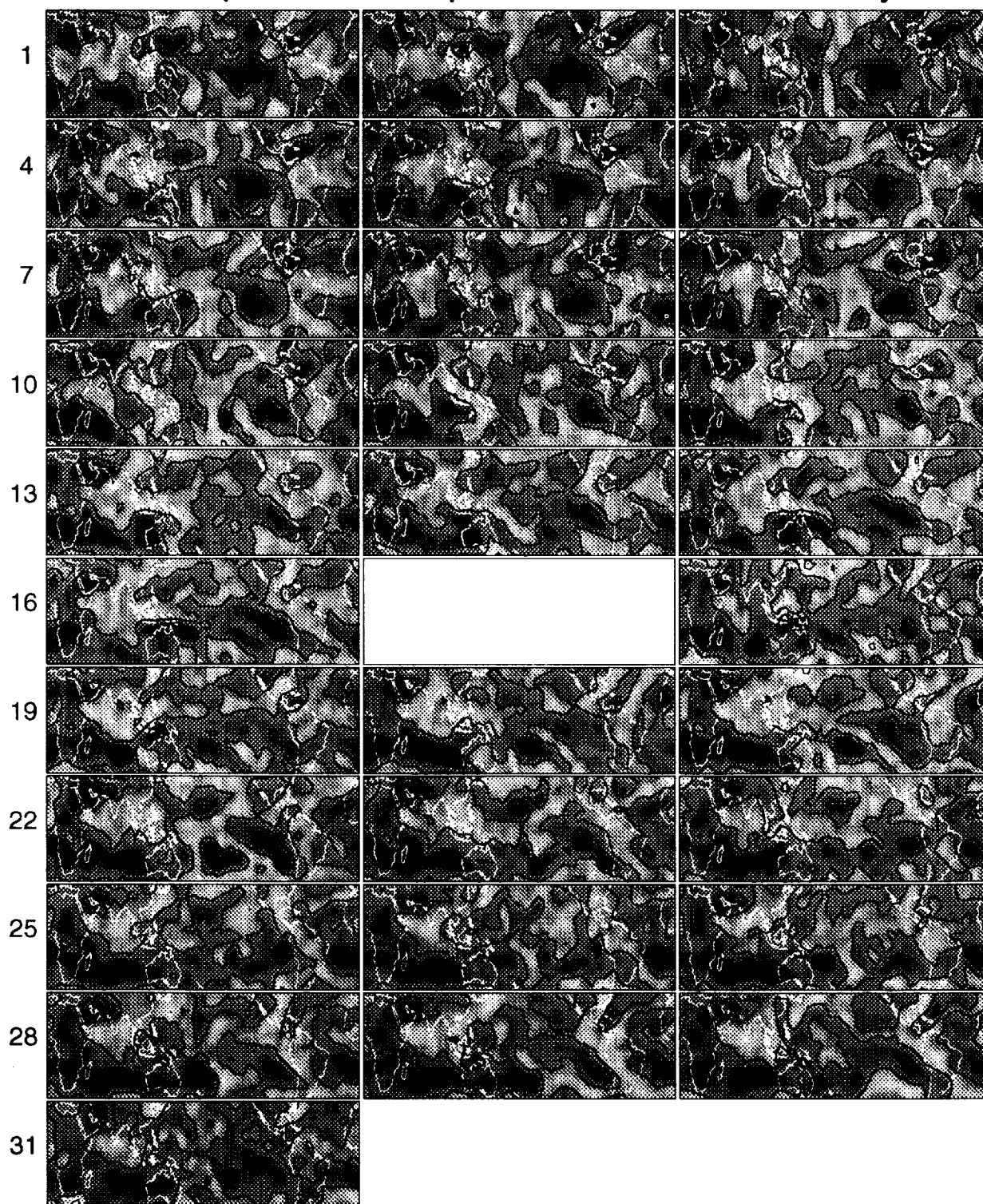
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A-225

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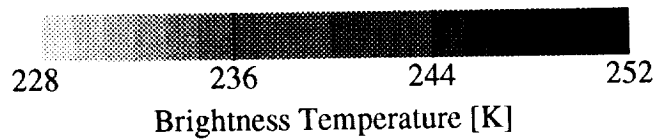
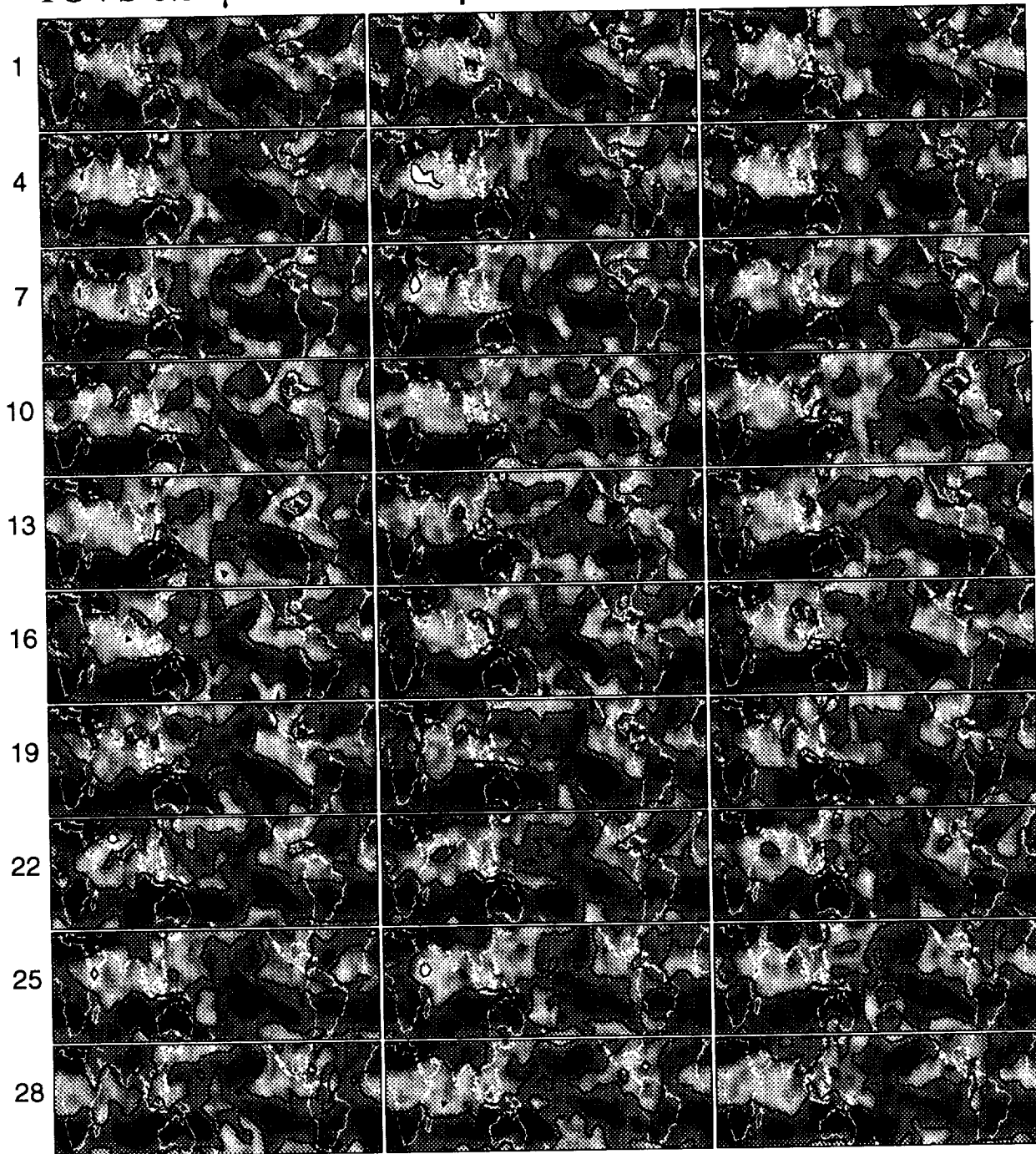
TOVS 6.5 μm Water Vapor Band

May 1988



TOVS 6.5 μm Water Vapor Band

June 1988



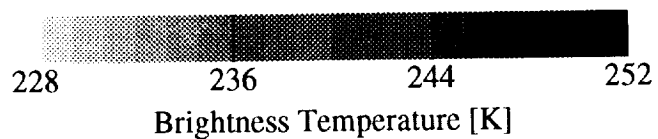
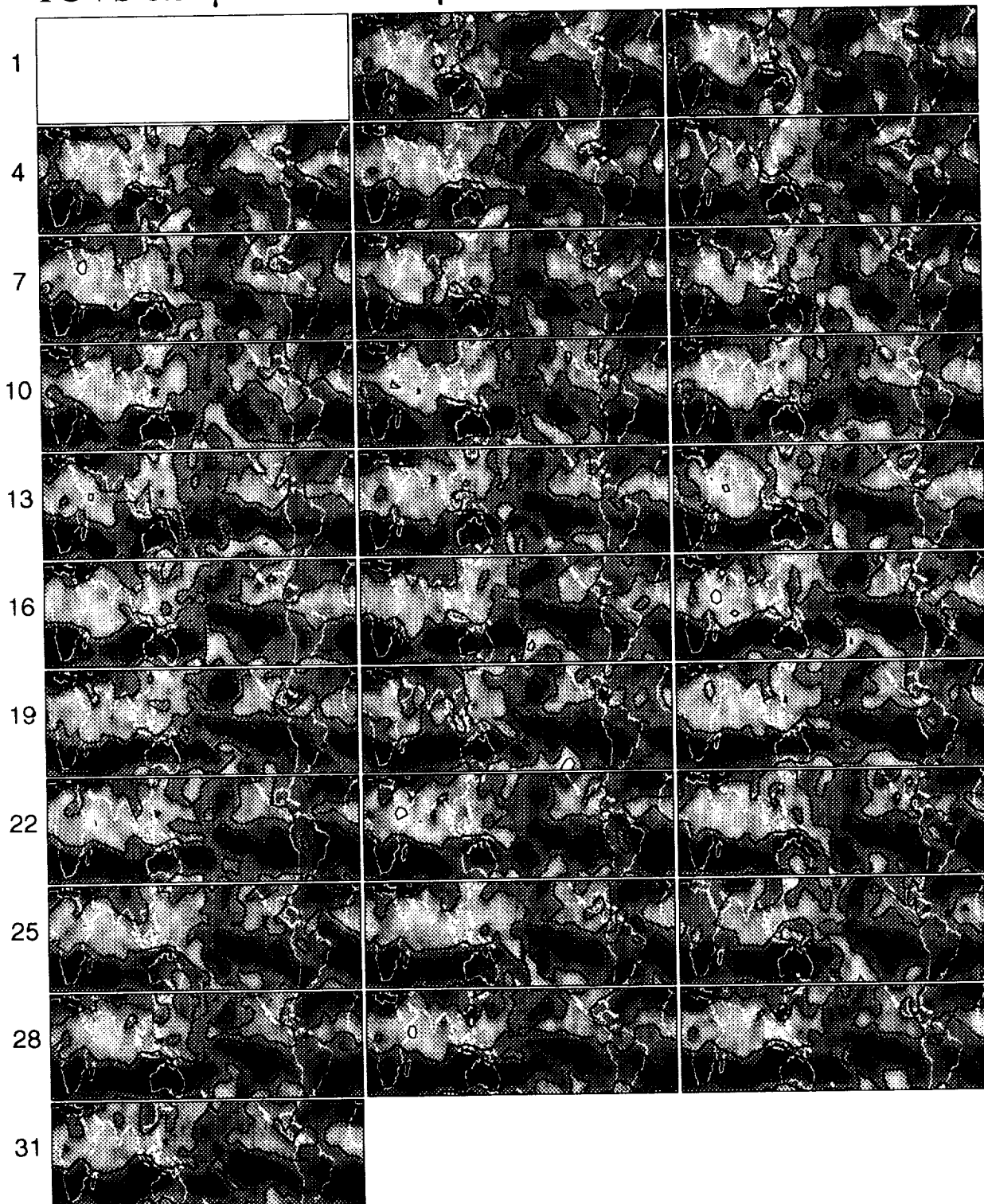
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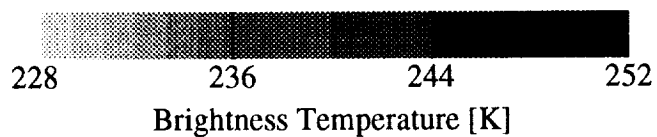
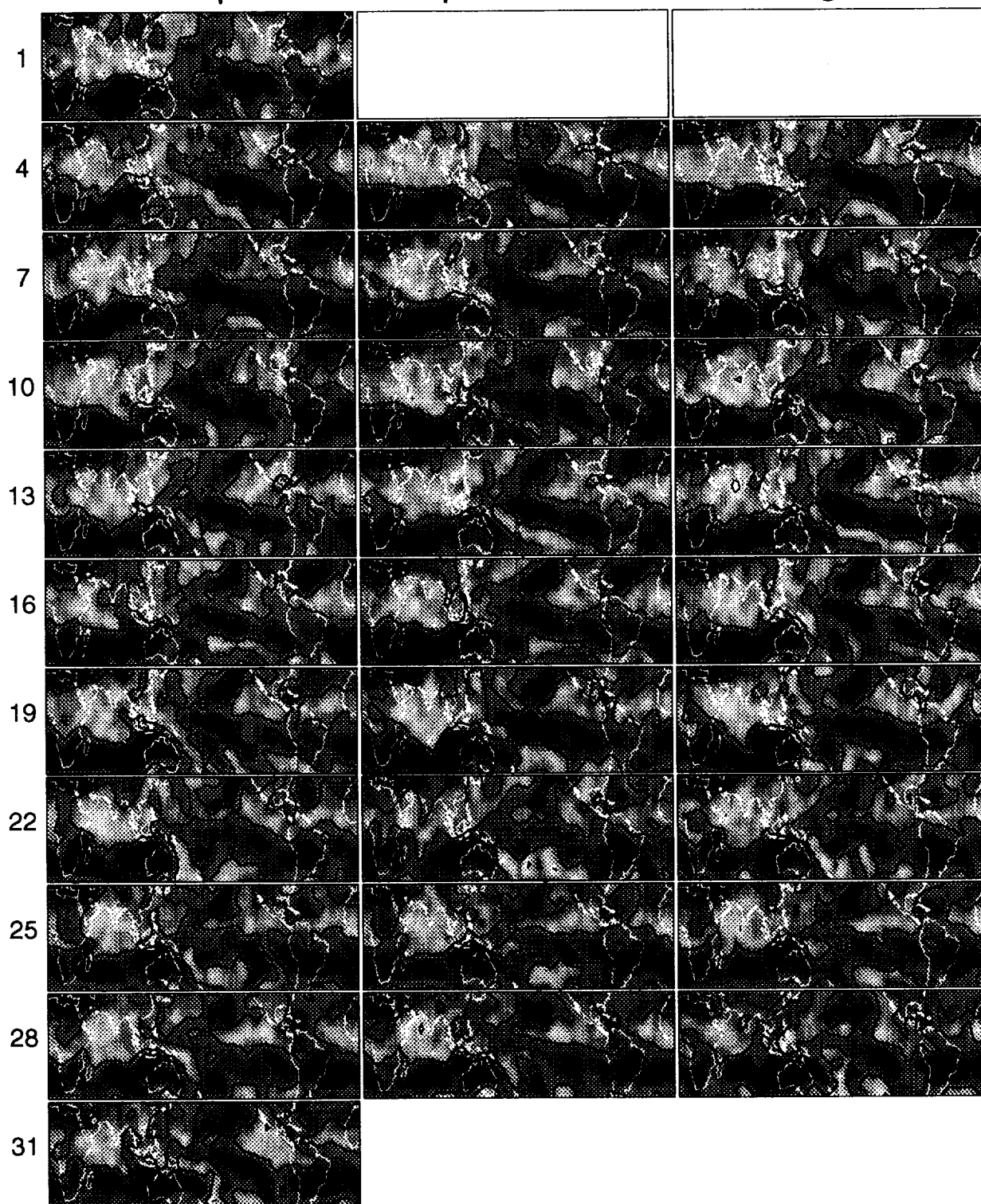
TOVS 6.5 μ m Water Vapor Band

July 1988



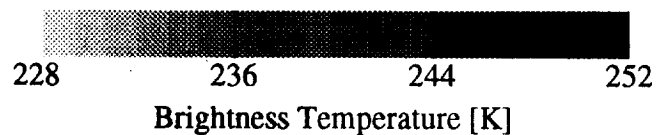
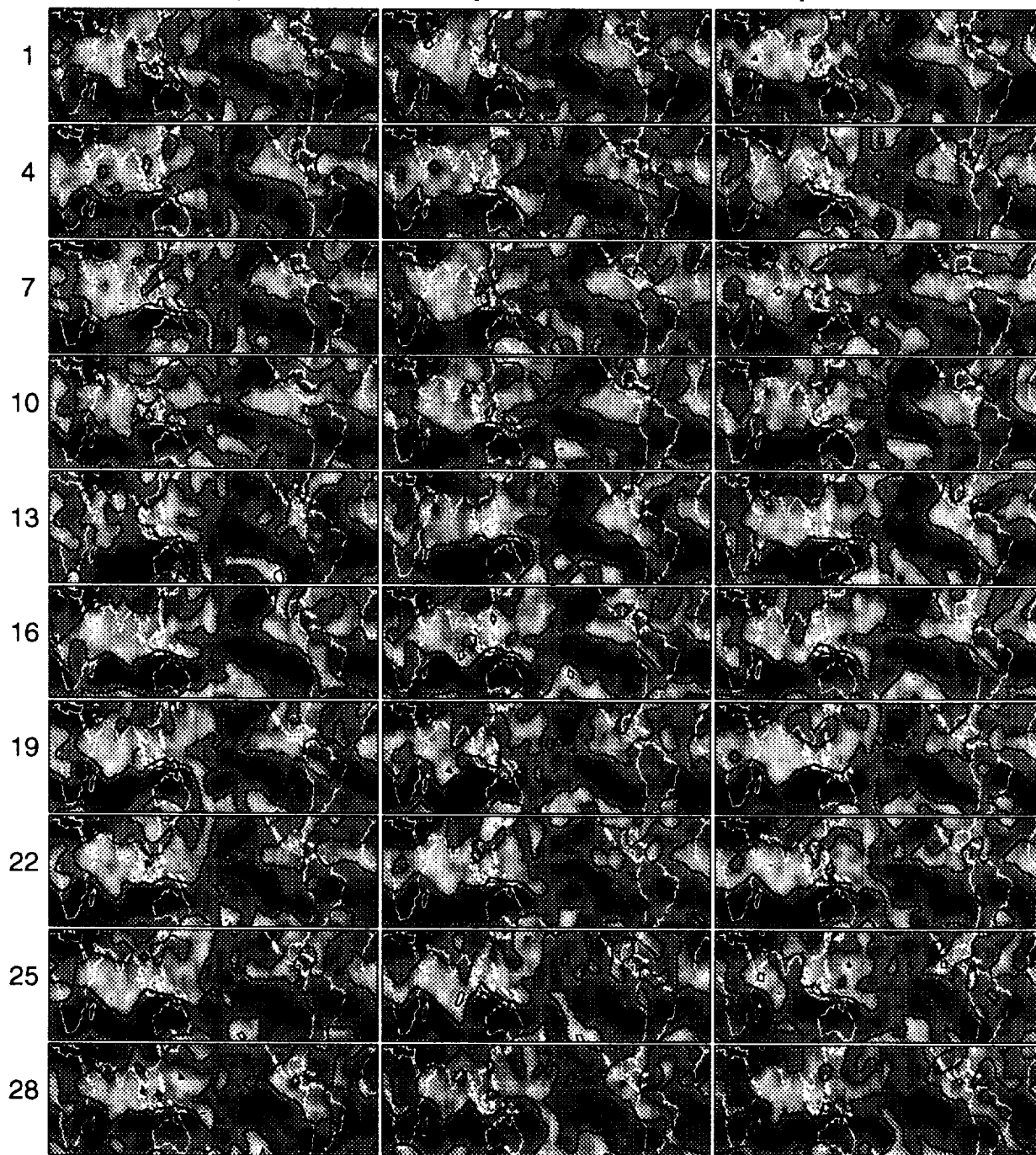
TOVS 6.5 μ m Water Vapor Band

August 1988



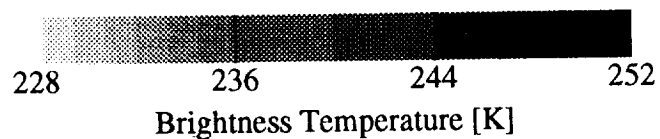
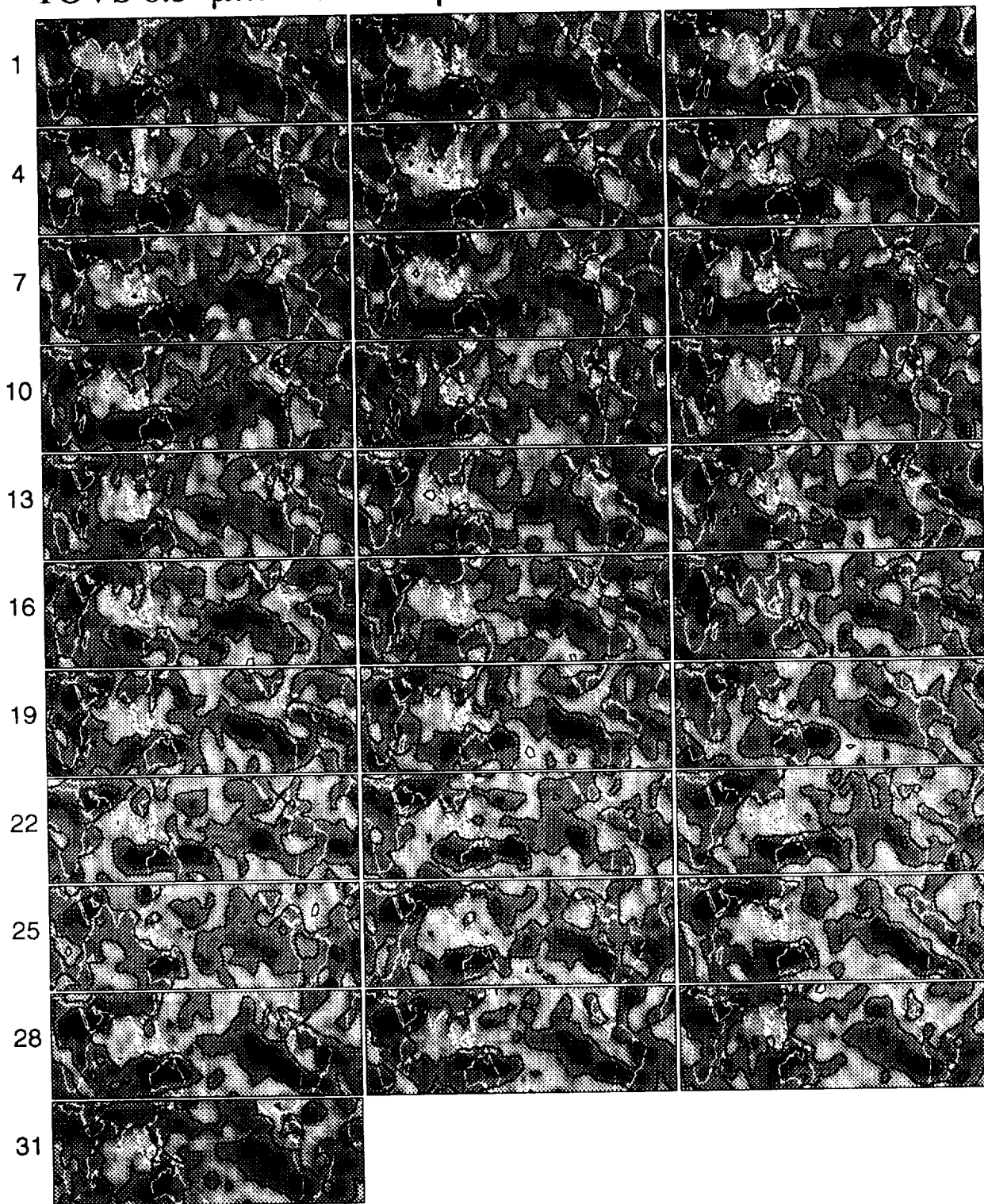
TOVS 6.5 μm Water Vapor Band

September 1988



TOVS 6.5 μm Water Vapor Band

October 1988



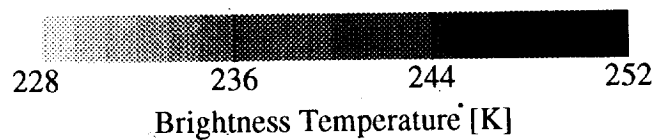
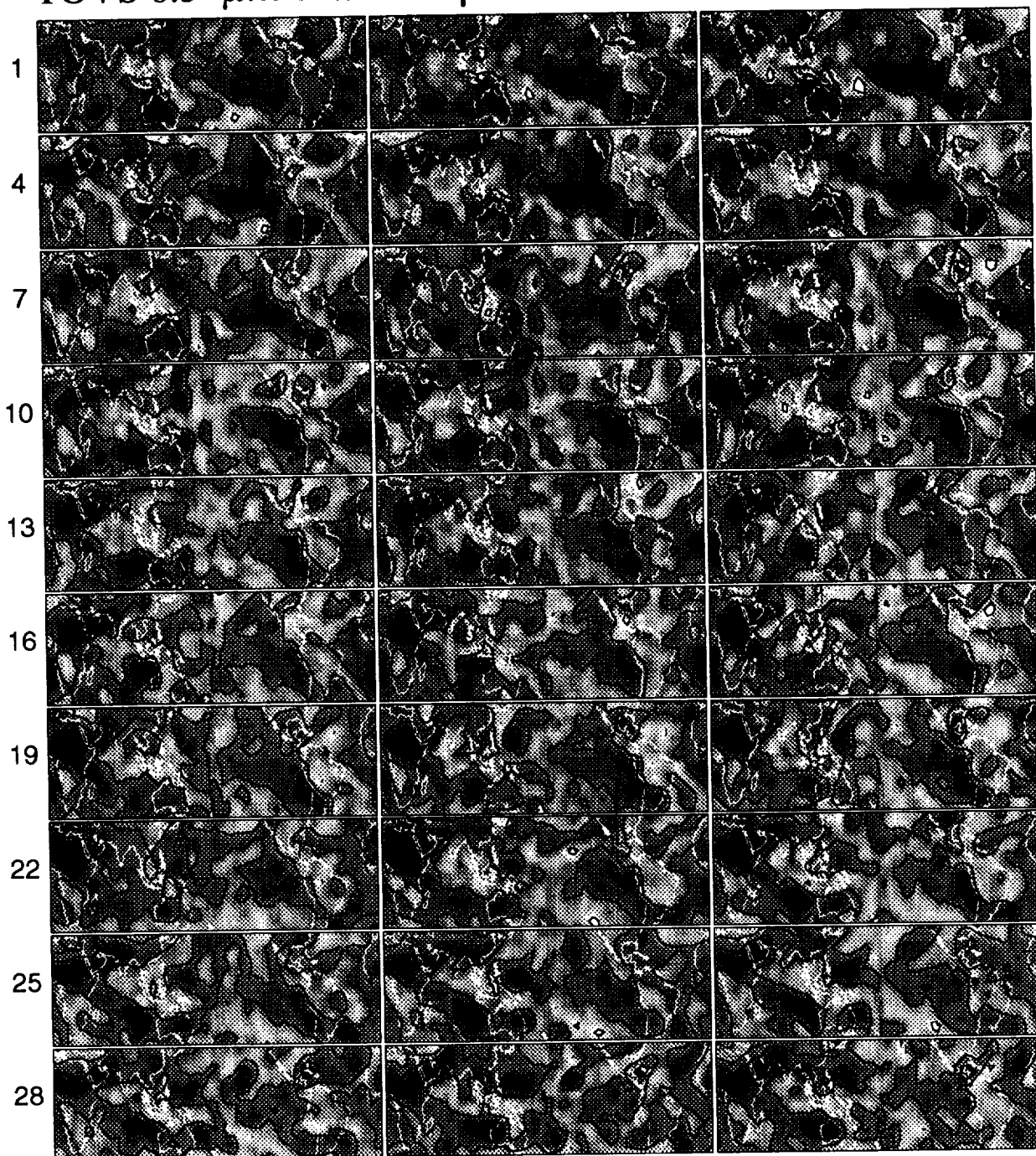
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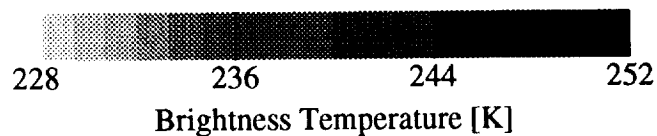
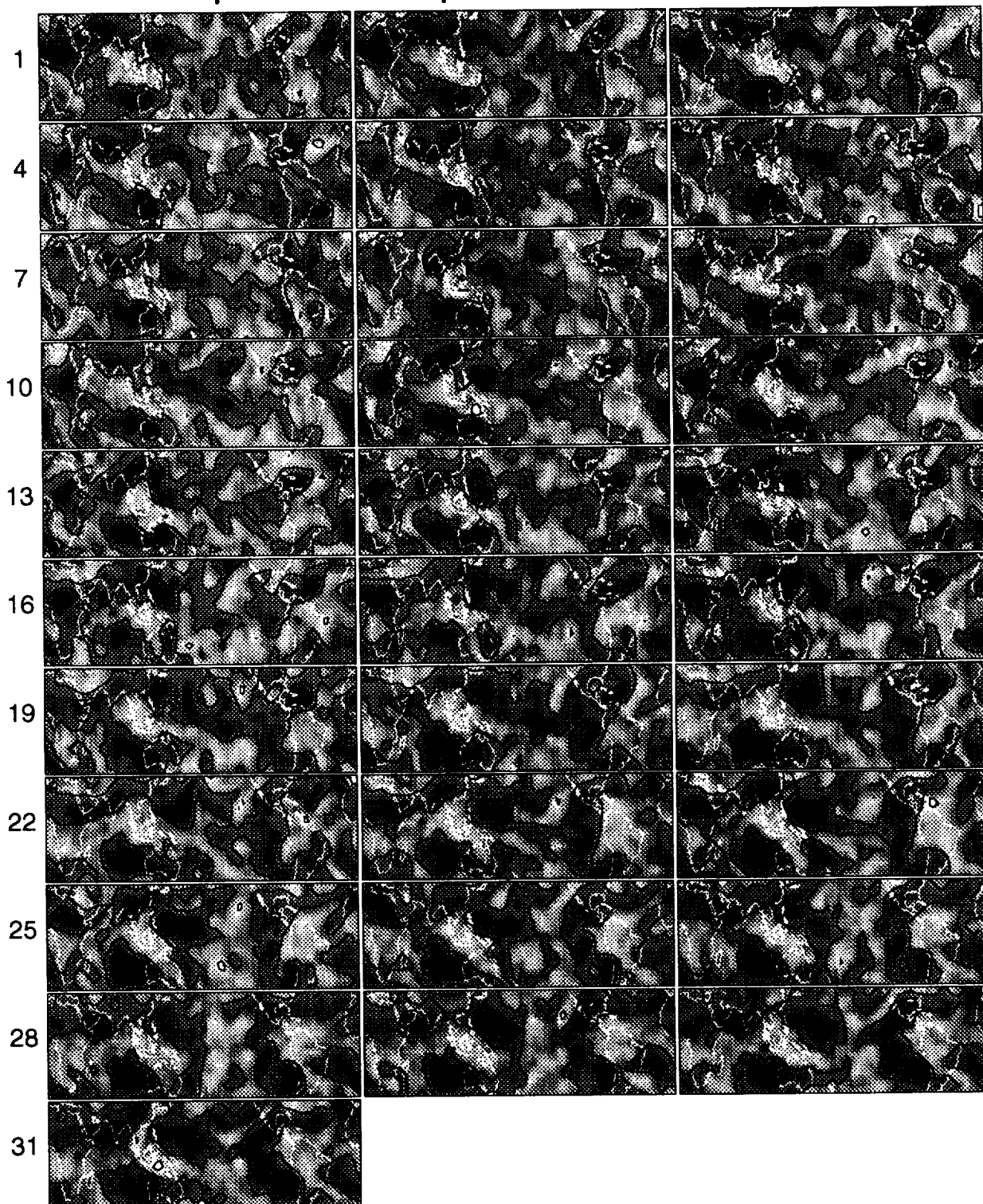
TOVS 6.5 μm Water Vapor Band

November 1988



TOVS 6.5 μm Water Vapor Band

December 1988



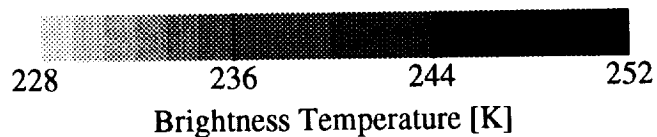
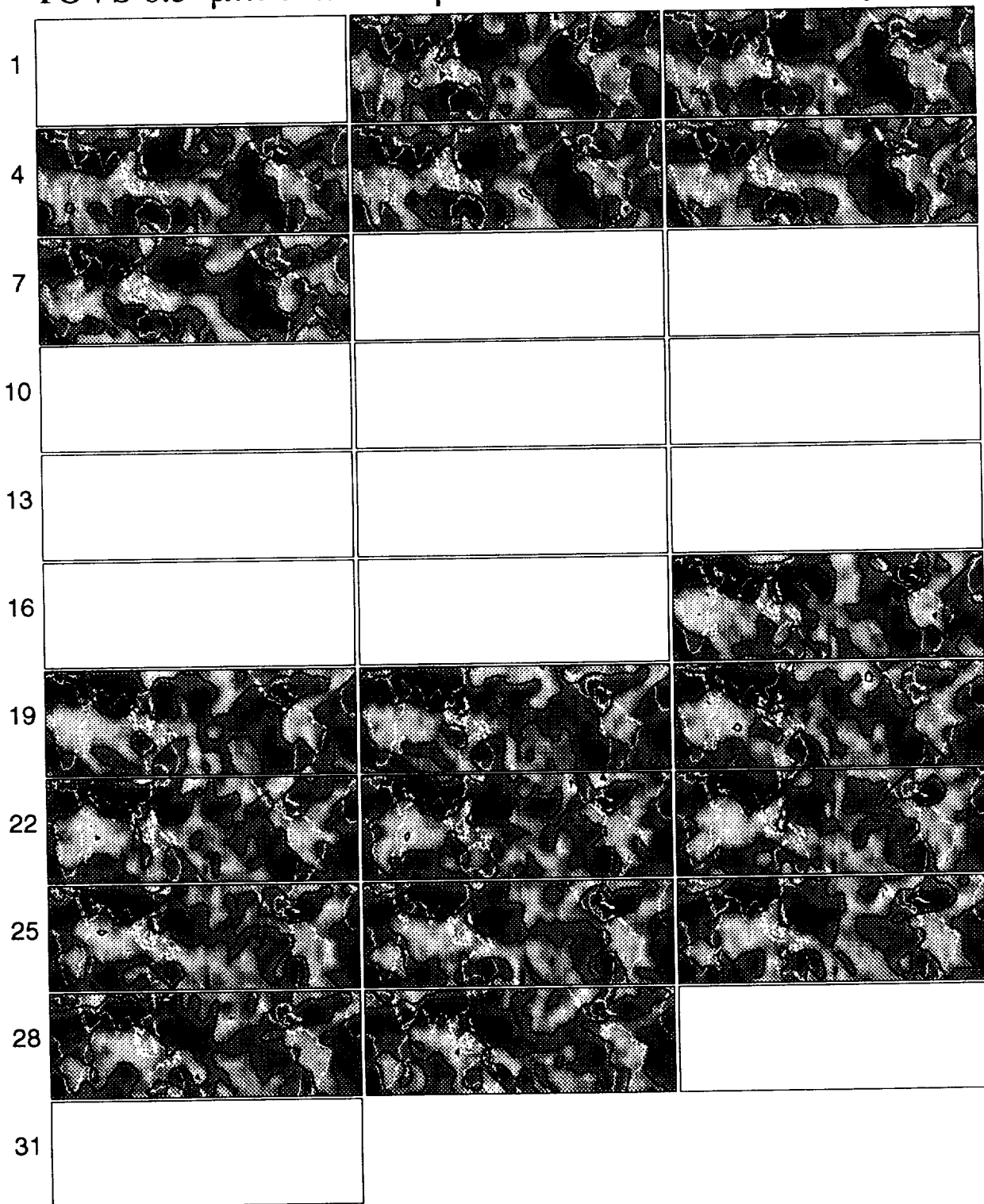
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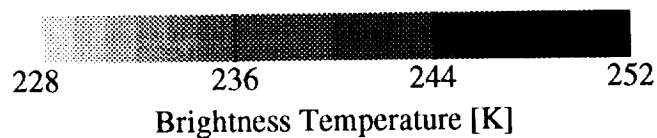
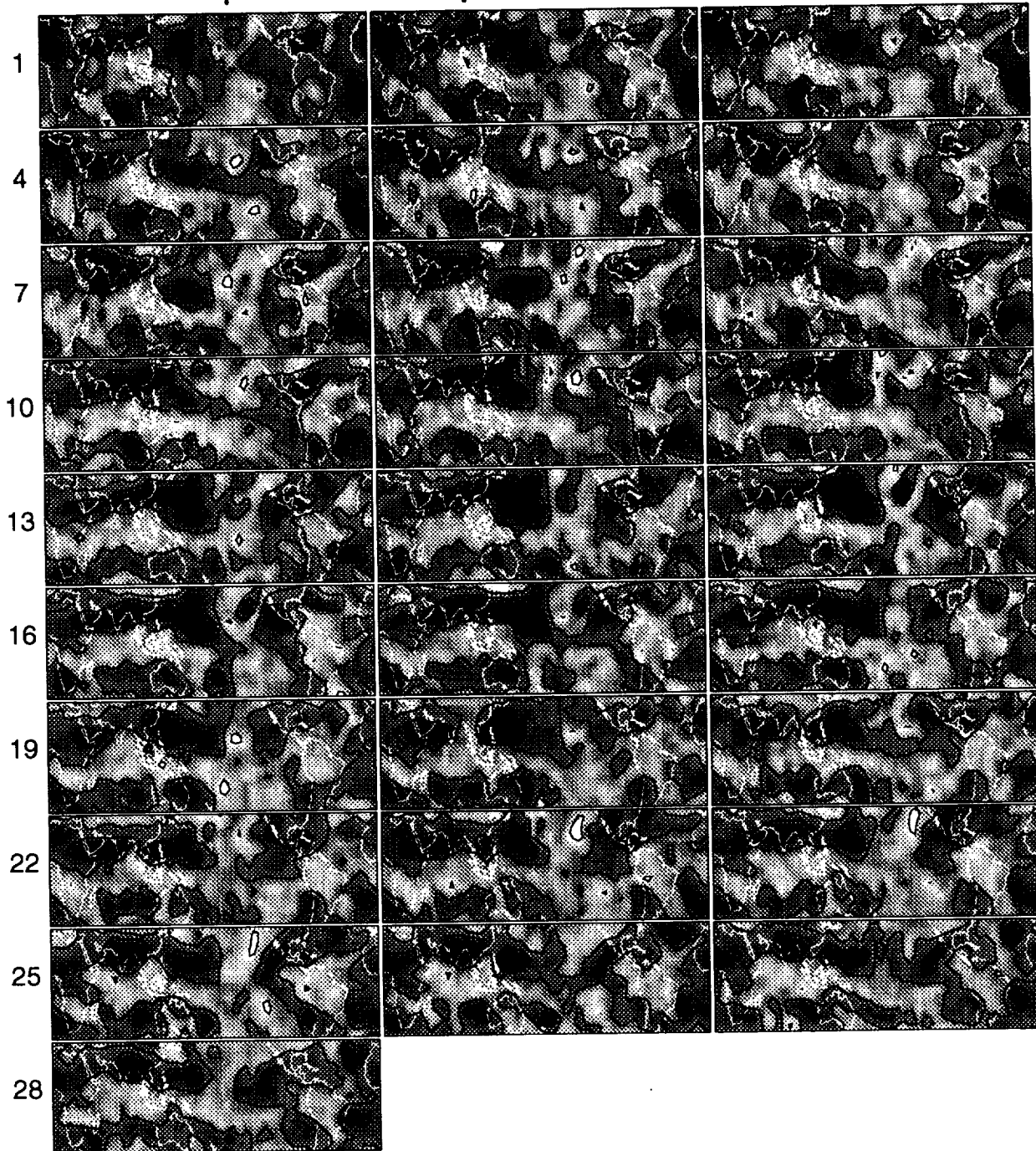
TOVS 6.5 μ m Water Vapor Band

January 1989



TOVS 6.5 μm Water Vapor Band

February 1989



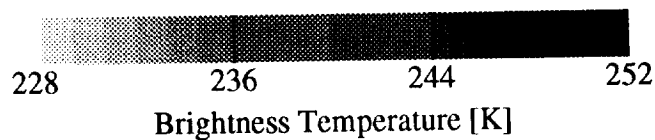
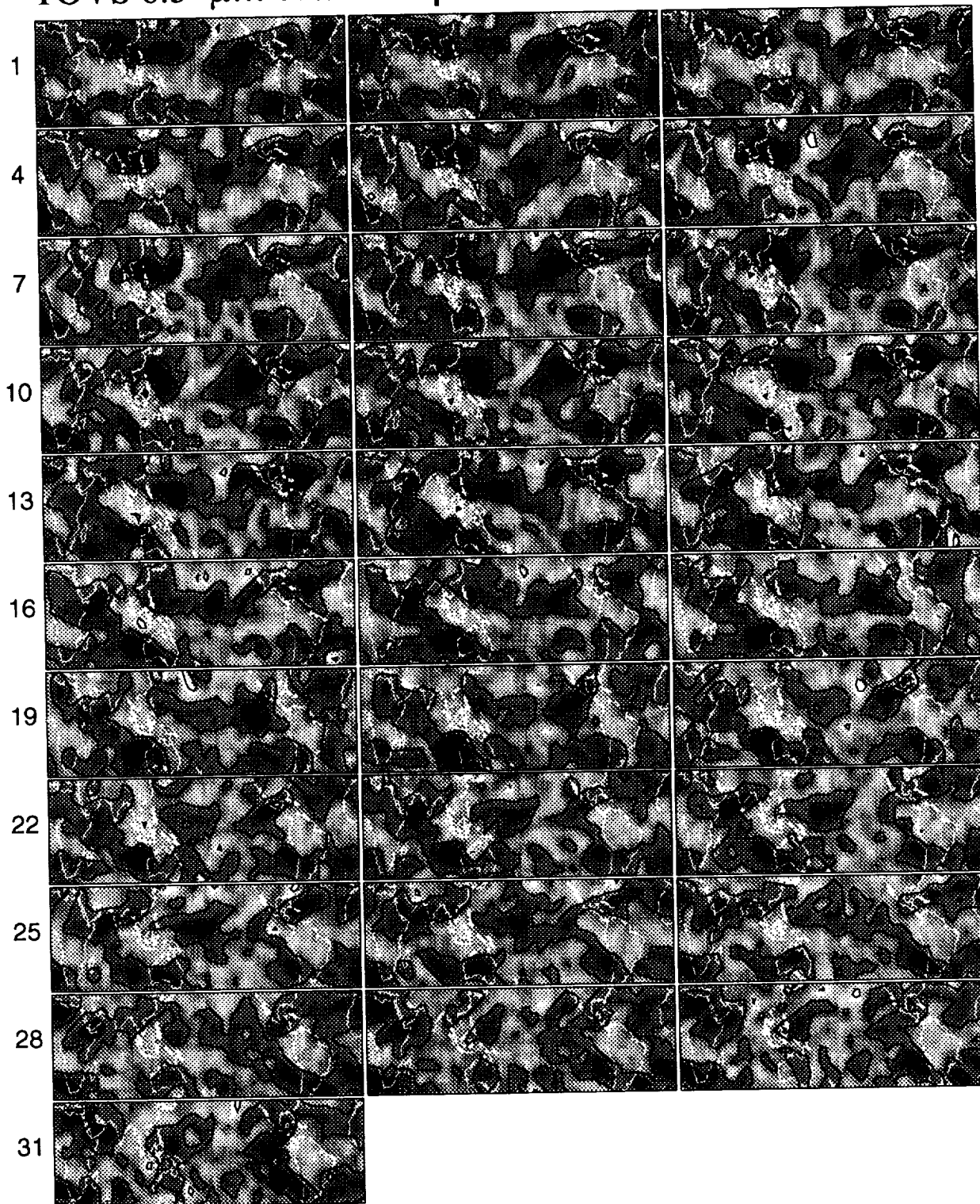
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62 A-244 INTENTIONALLY BLANK

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TOVS 6.5 μm Water Vapor Band

March 1989



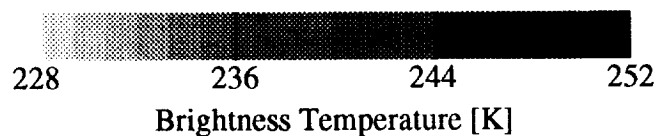
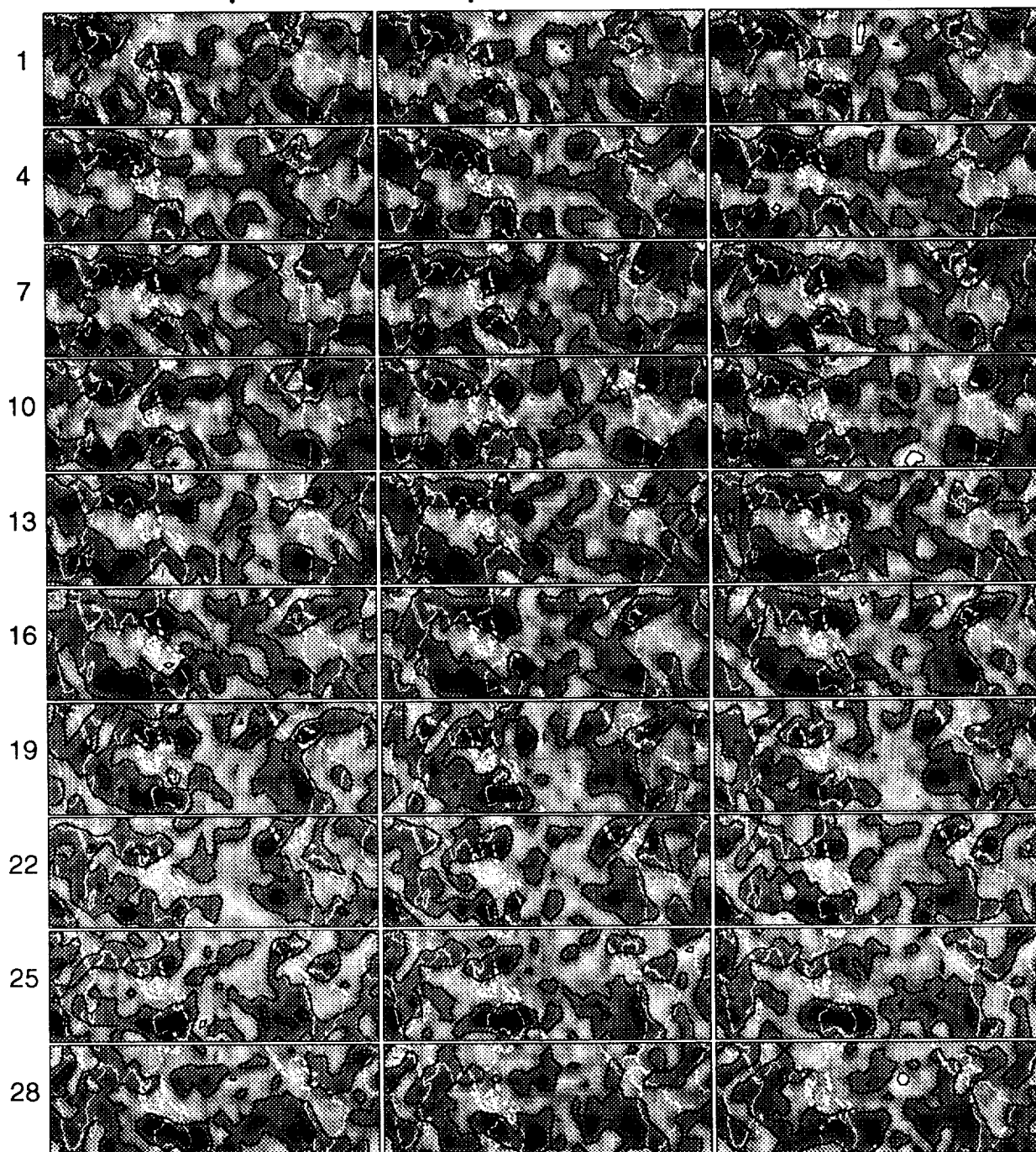
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A-247

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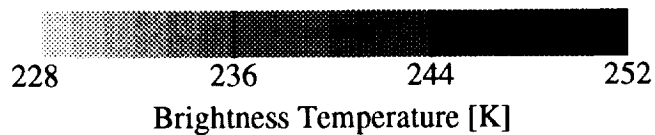
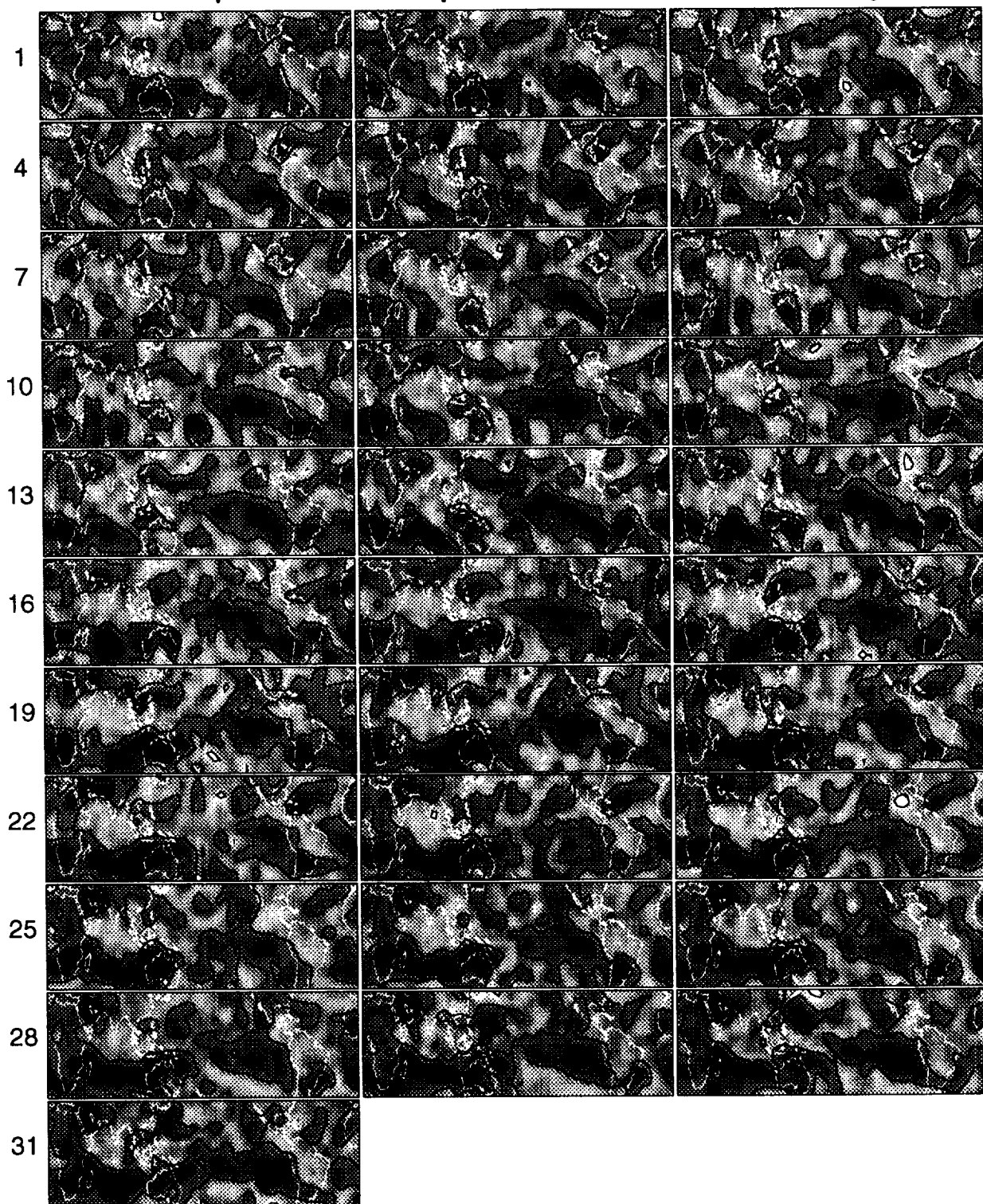
TOVS 6.5 μm Water Vapor Band

April 1989



TOVS 6.5 μm Water Vapor Band

May 1989

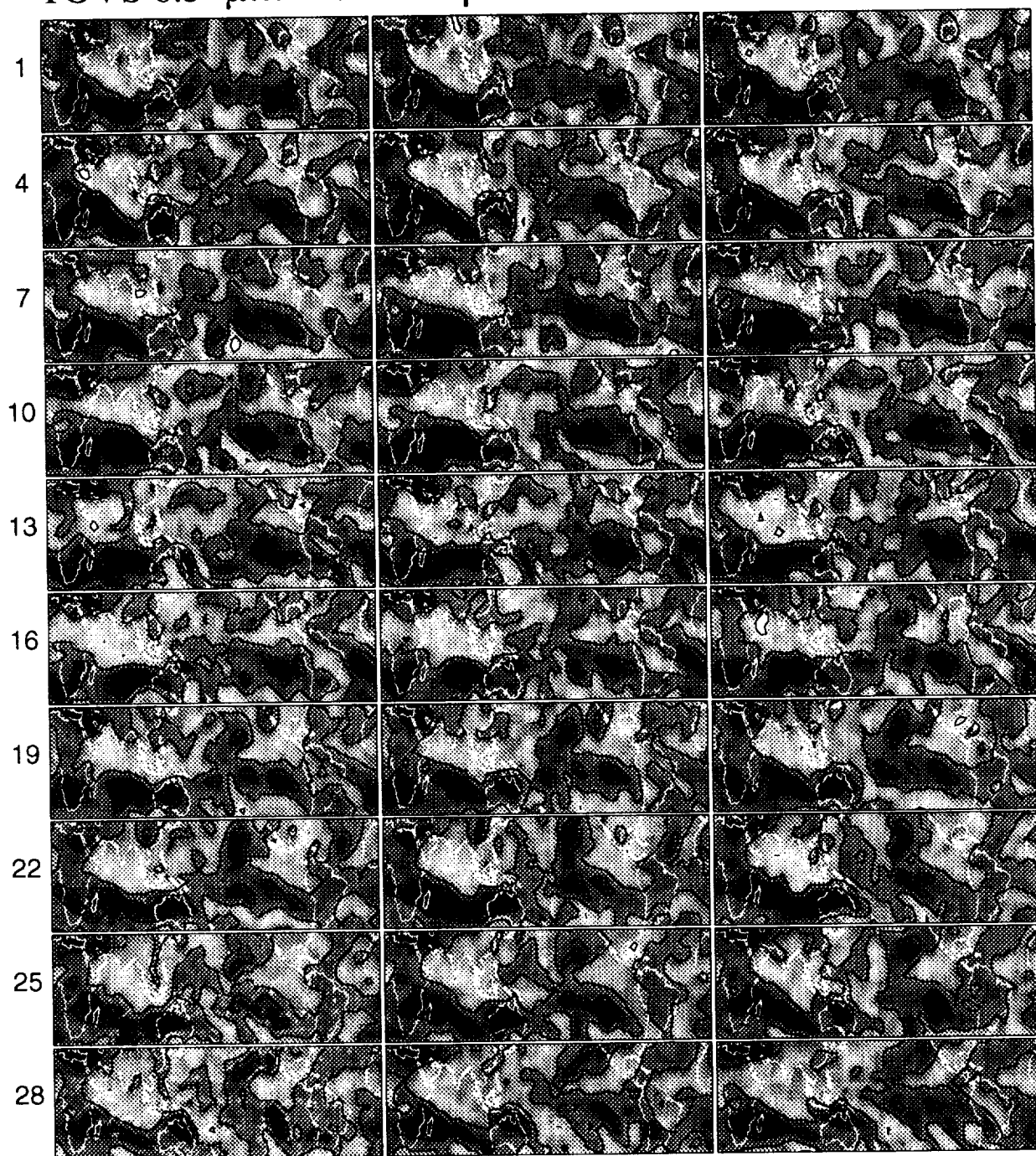


A-251

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June 1989



228 236 244 252

Brightness Temperature [K]

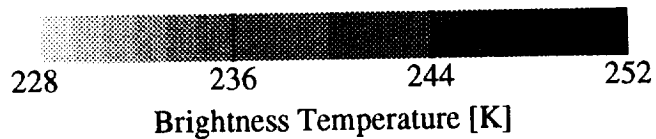
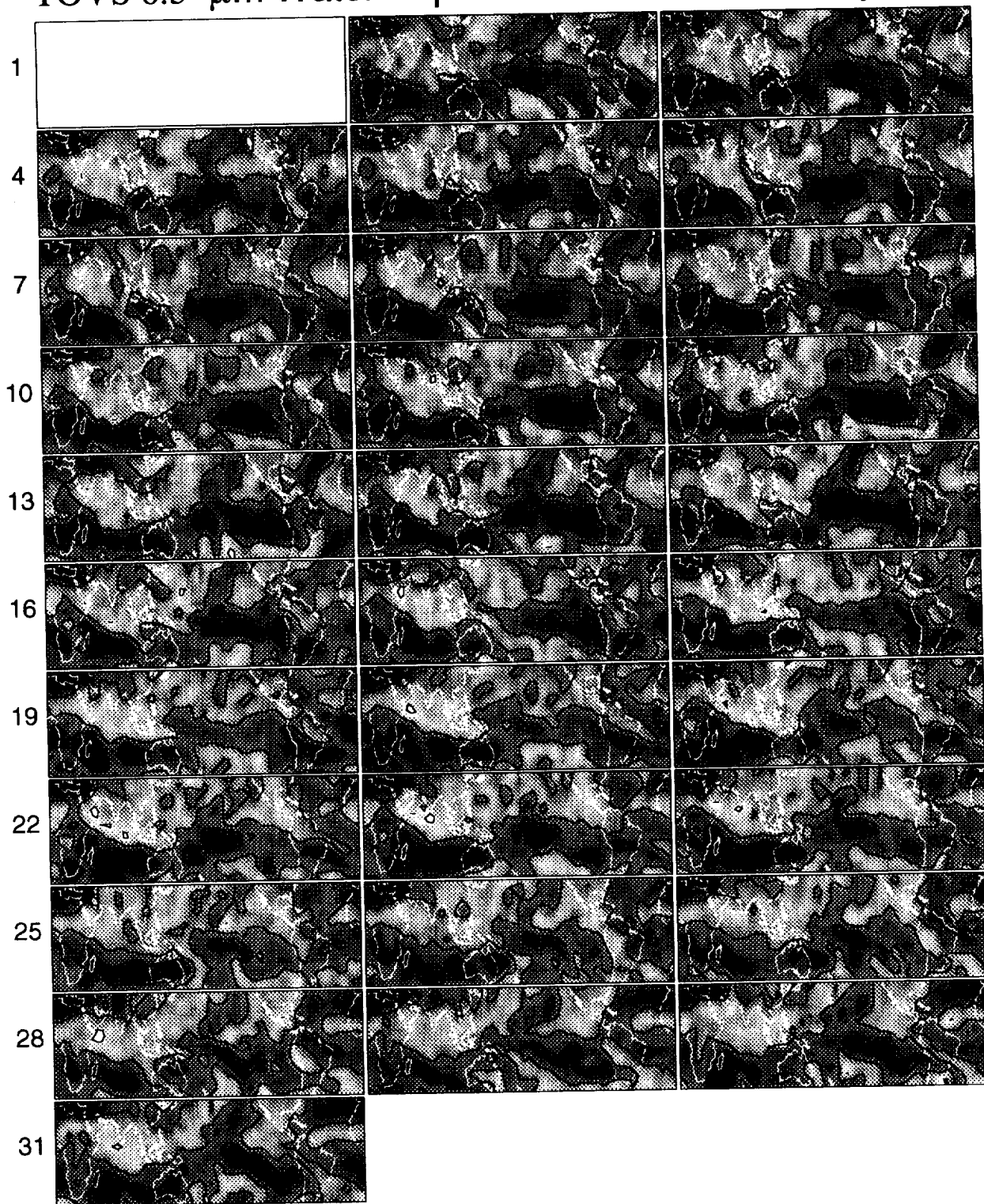
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[illegible]

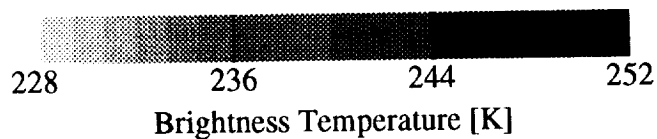
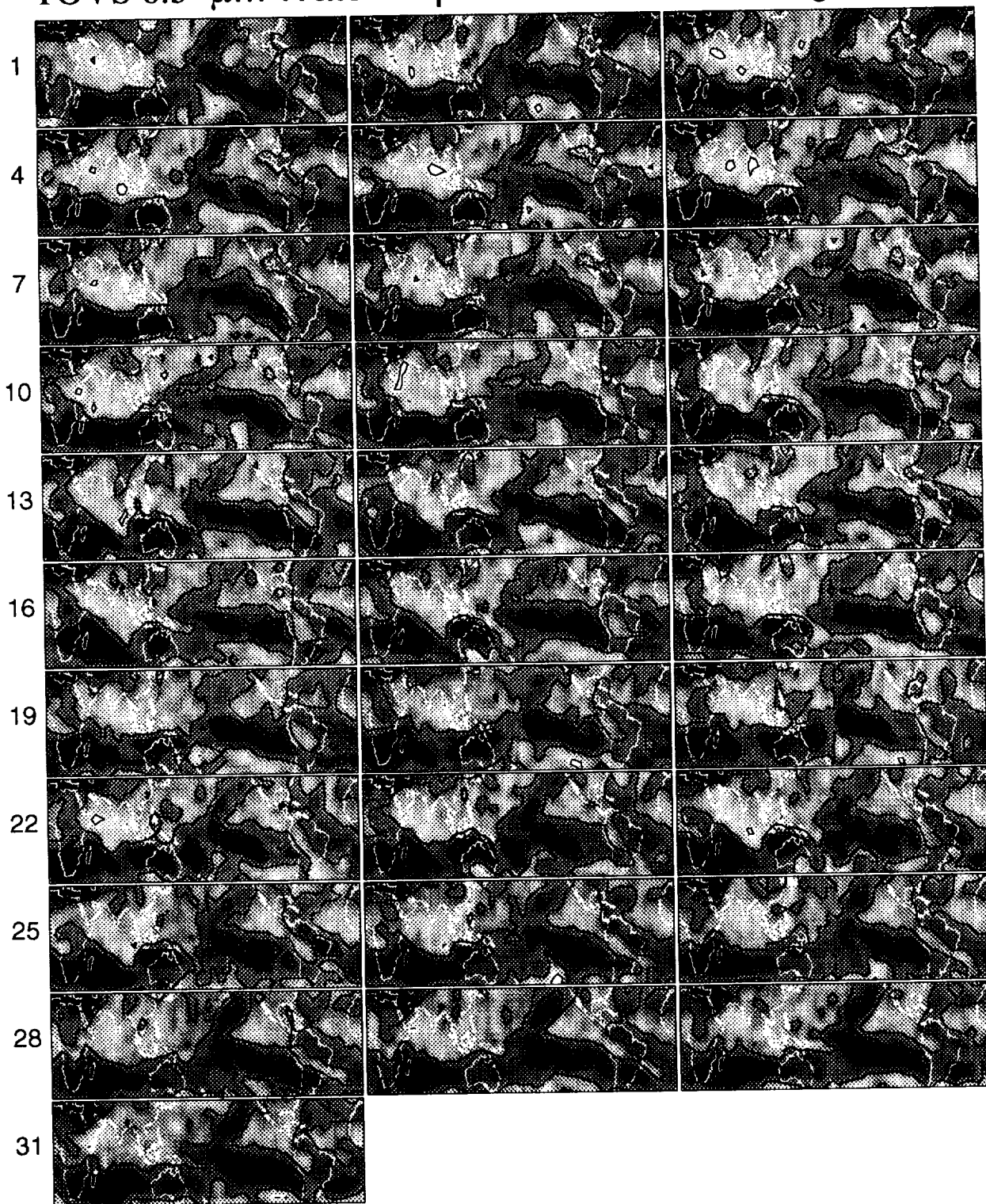
TOVS 6.5 μm Water Vapor Band

July 1989



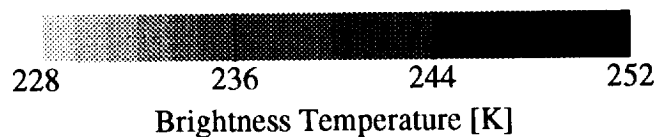
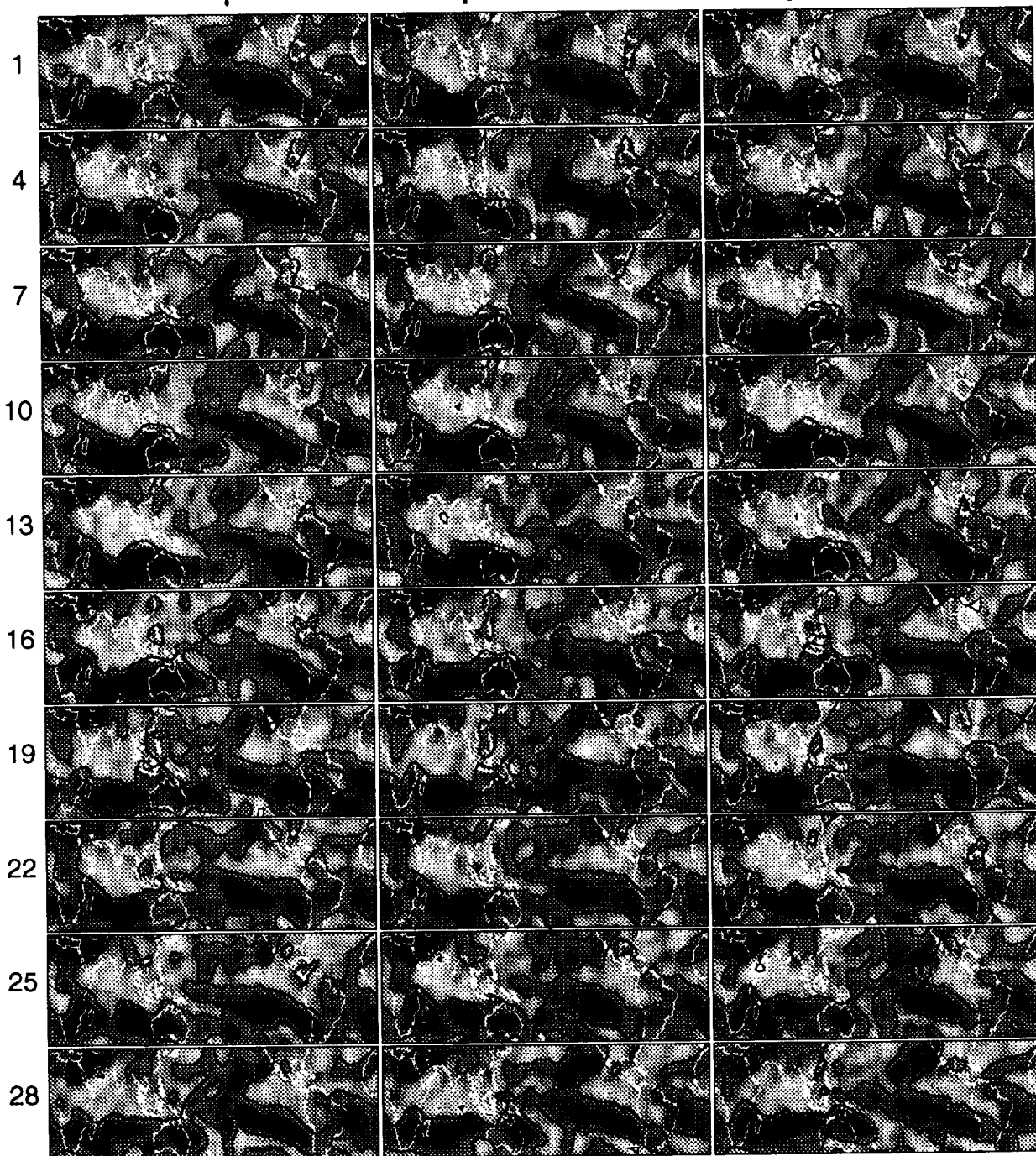
TOVS 6.5 μm Water Vapor Band

August 1989



TOVS 6.5 μm Water Vapor Band

September 1989



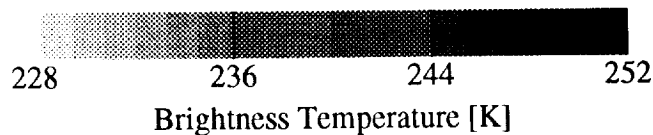
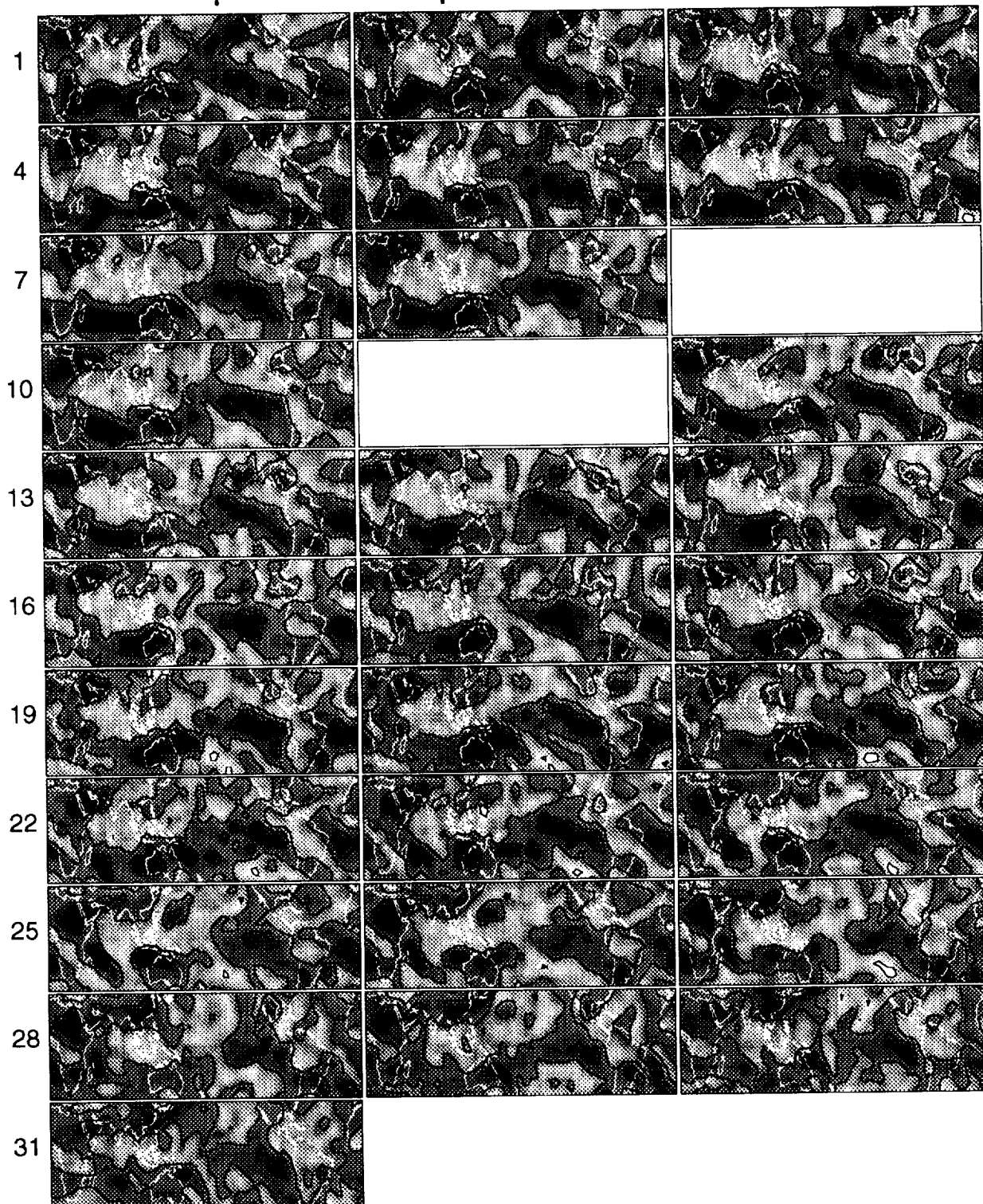
A-259

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TOVS 6.5 μm Water Vapor Band

October 1989



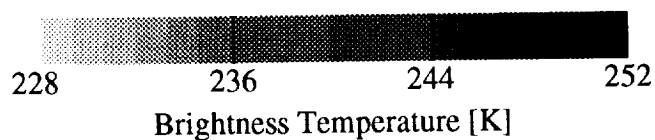
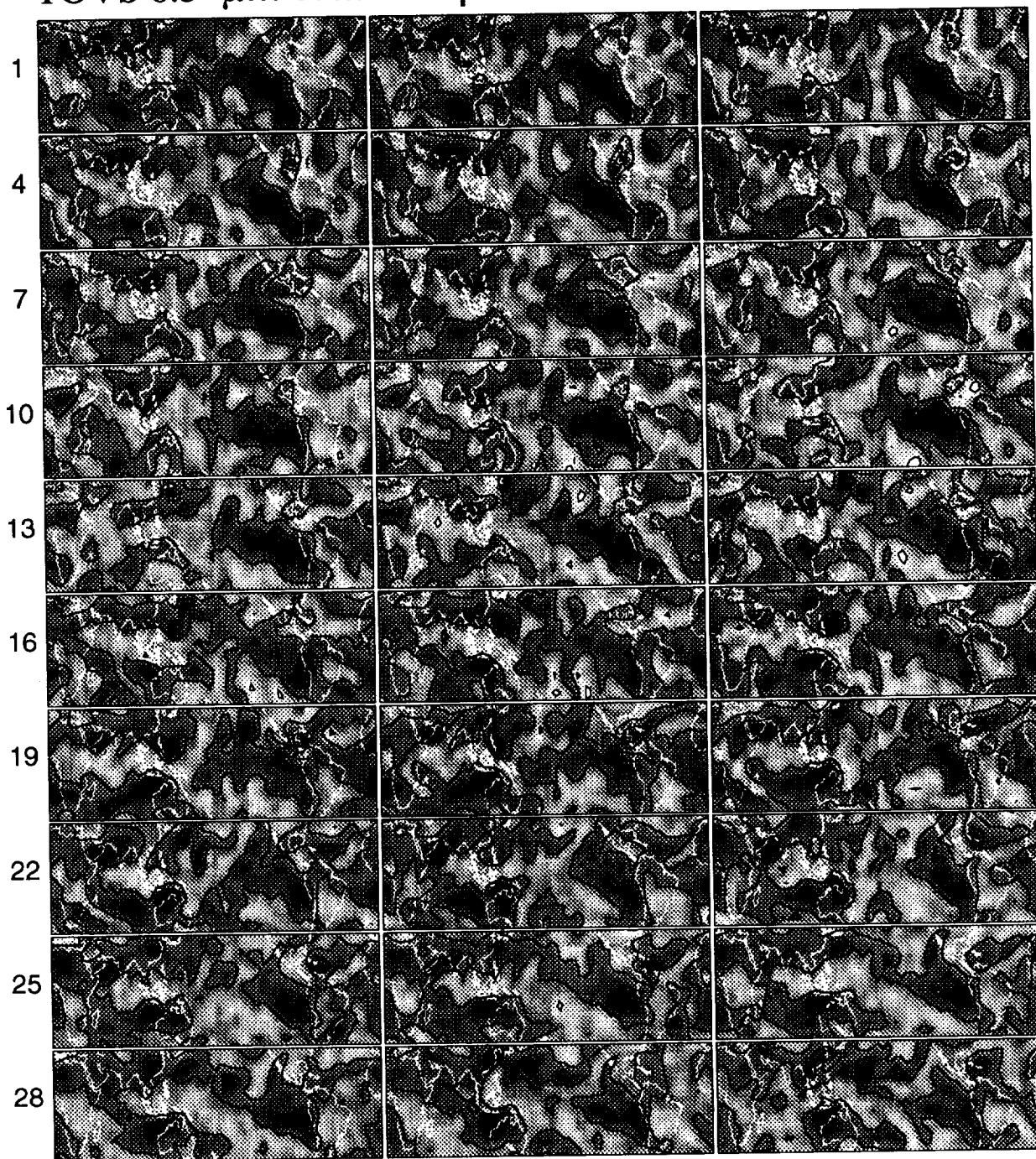
A-261

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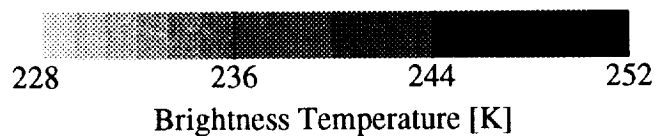
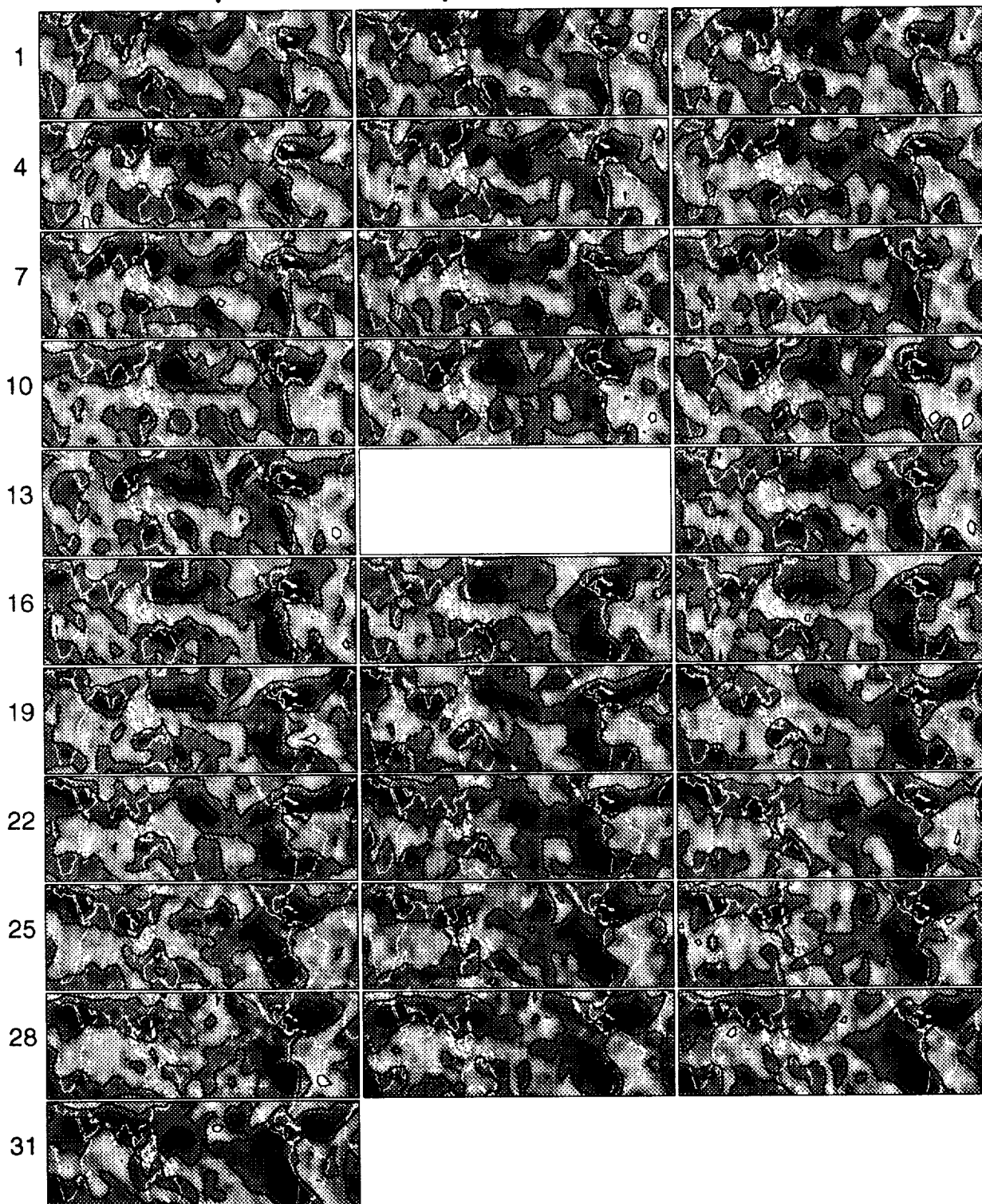
TOVS 6.5 μm Water Vapor Band

November 1989



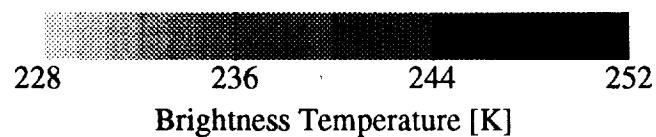
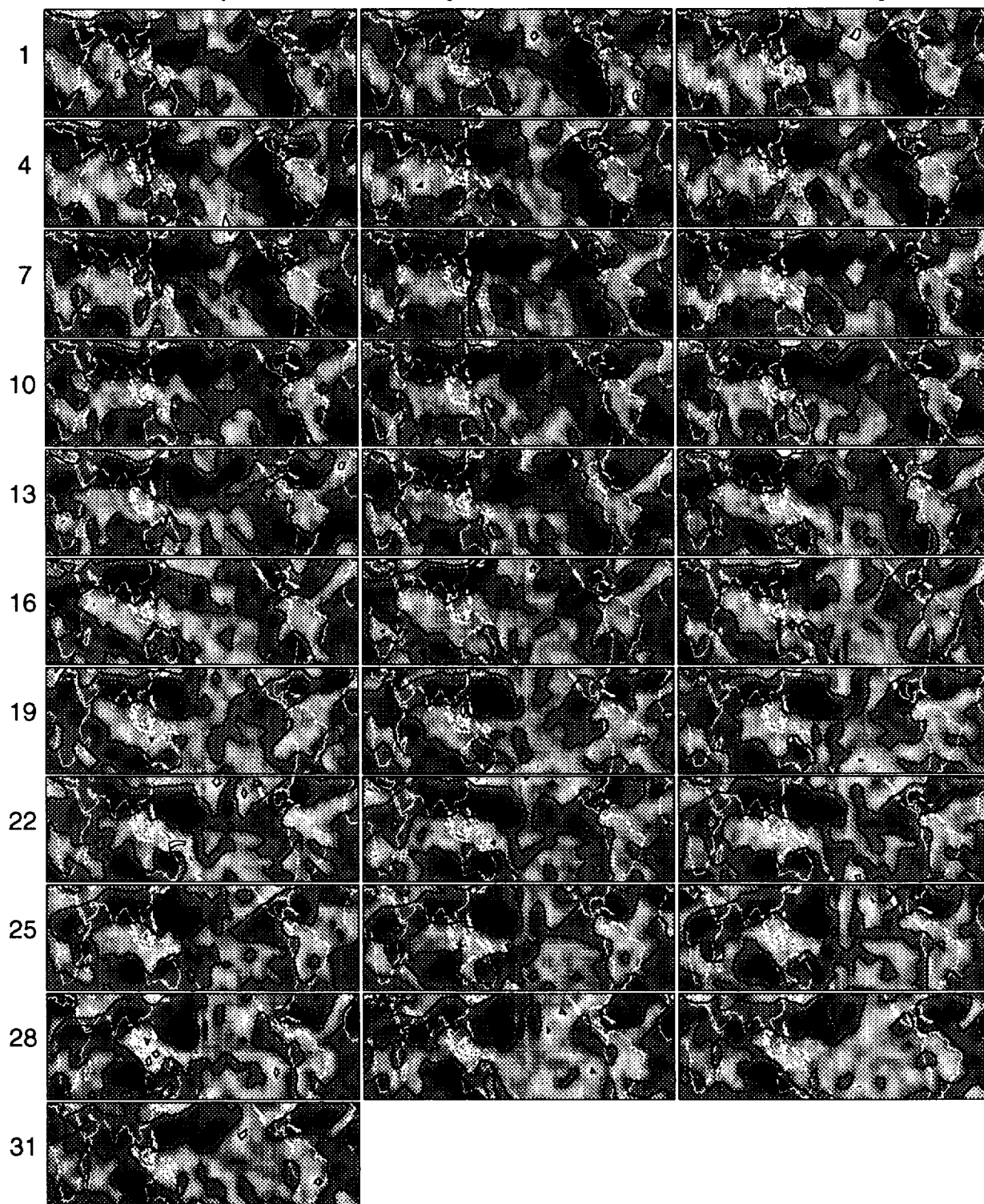
TOVS 6.5 μ m Water Vapor Band

December 1989



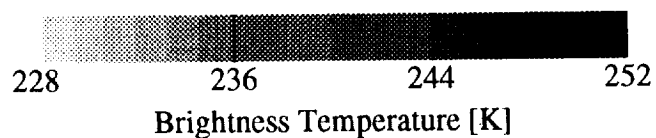
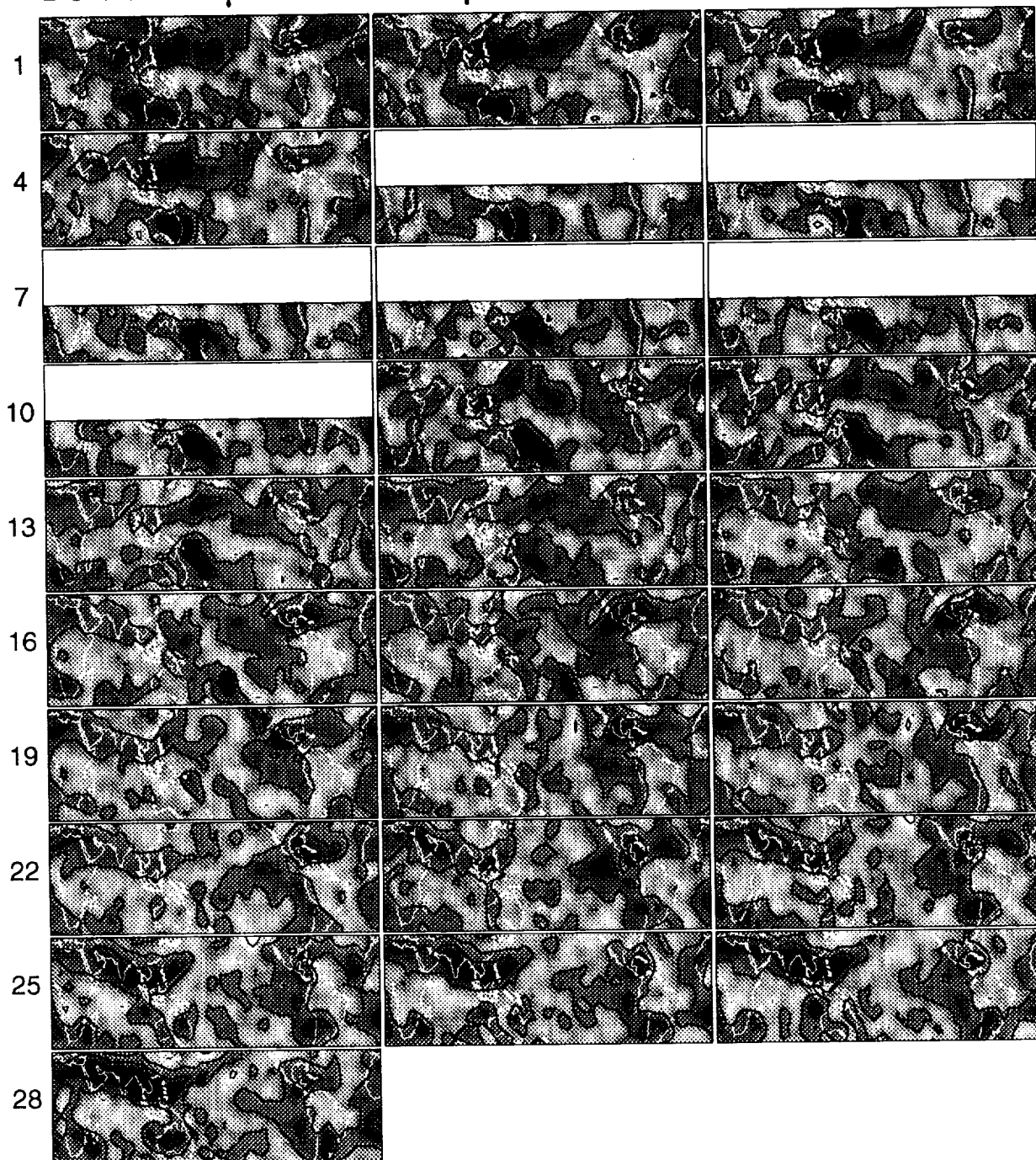
TOVS 6.5 μm Water Vapor Band

January 1990



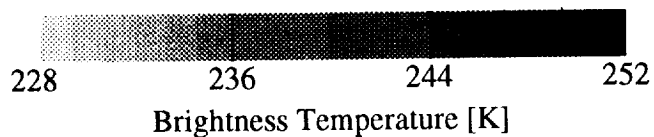
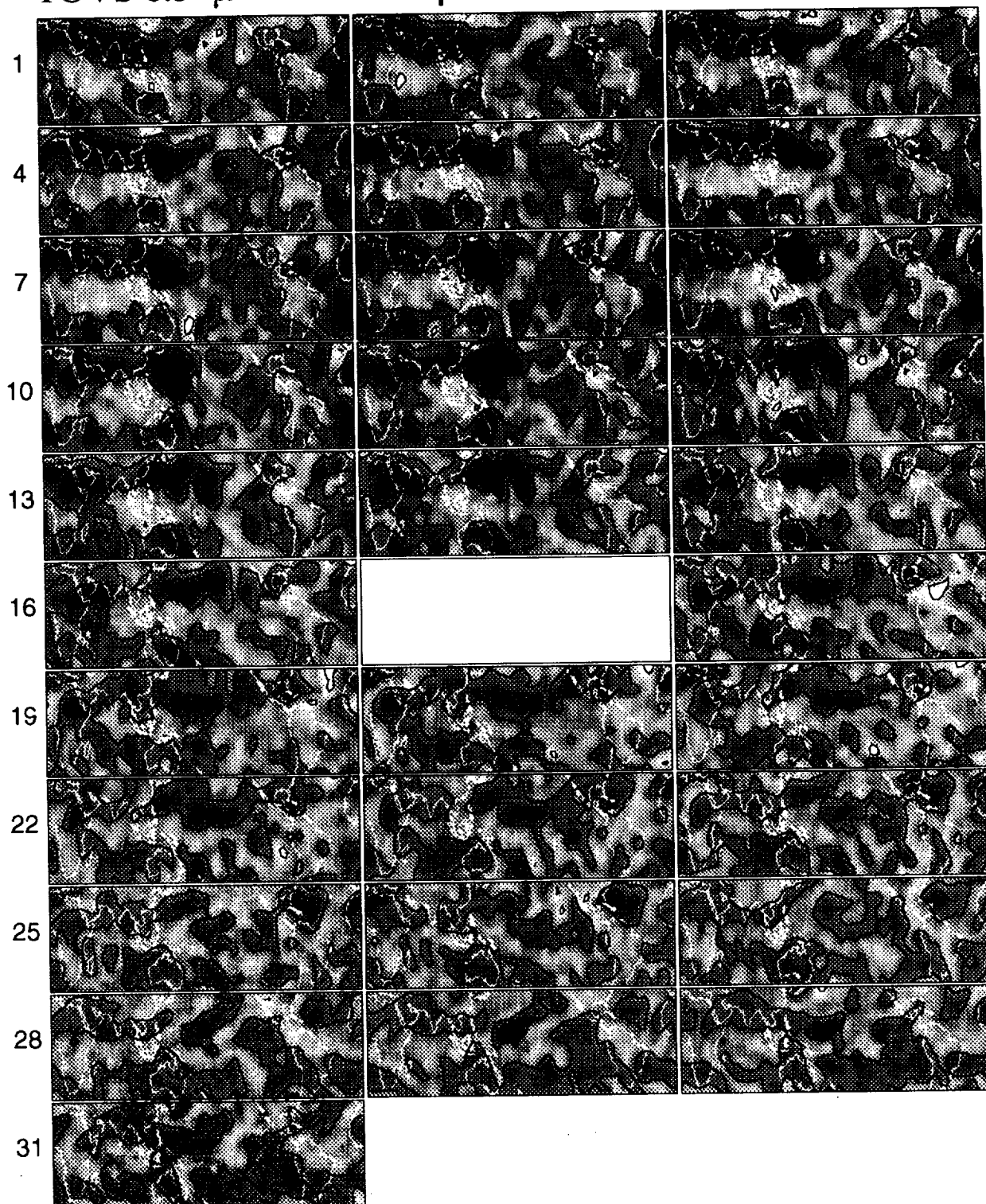
TOVS 6.5 μm Water Vapor Band

February 1990



TOVS 6.5 μm Water Vapor Band

March 1990



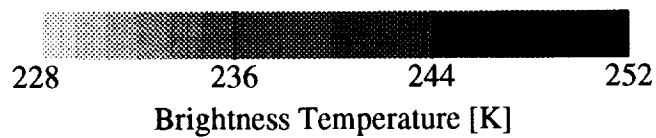
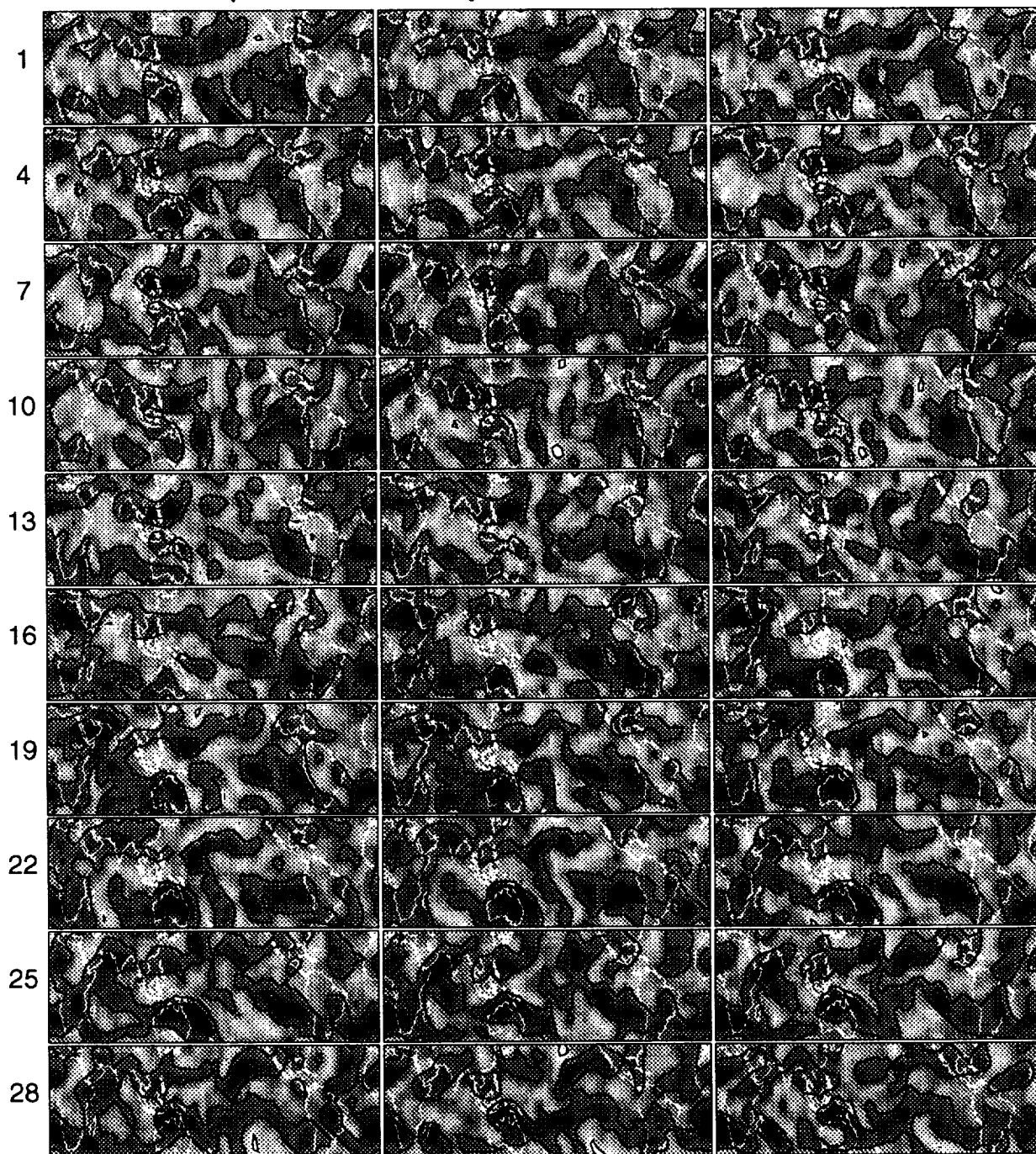
A-271

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FORM A-270 INVENTOR

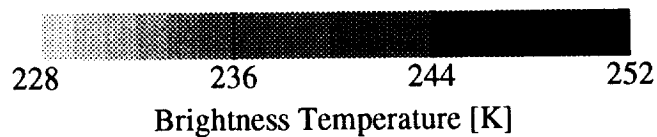
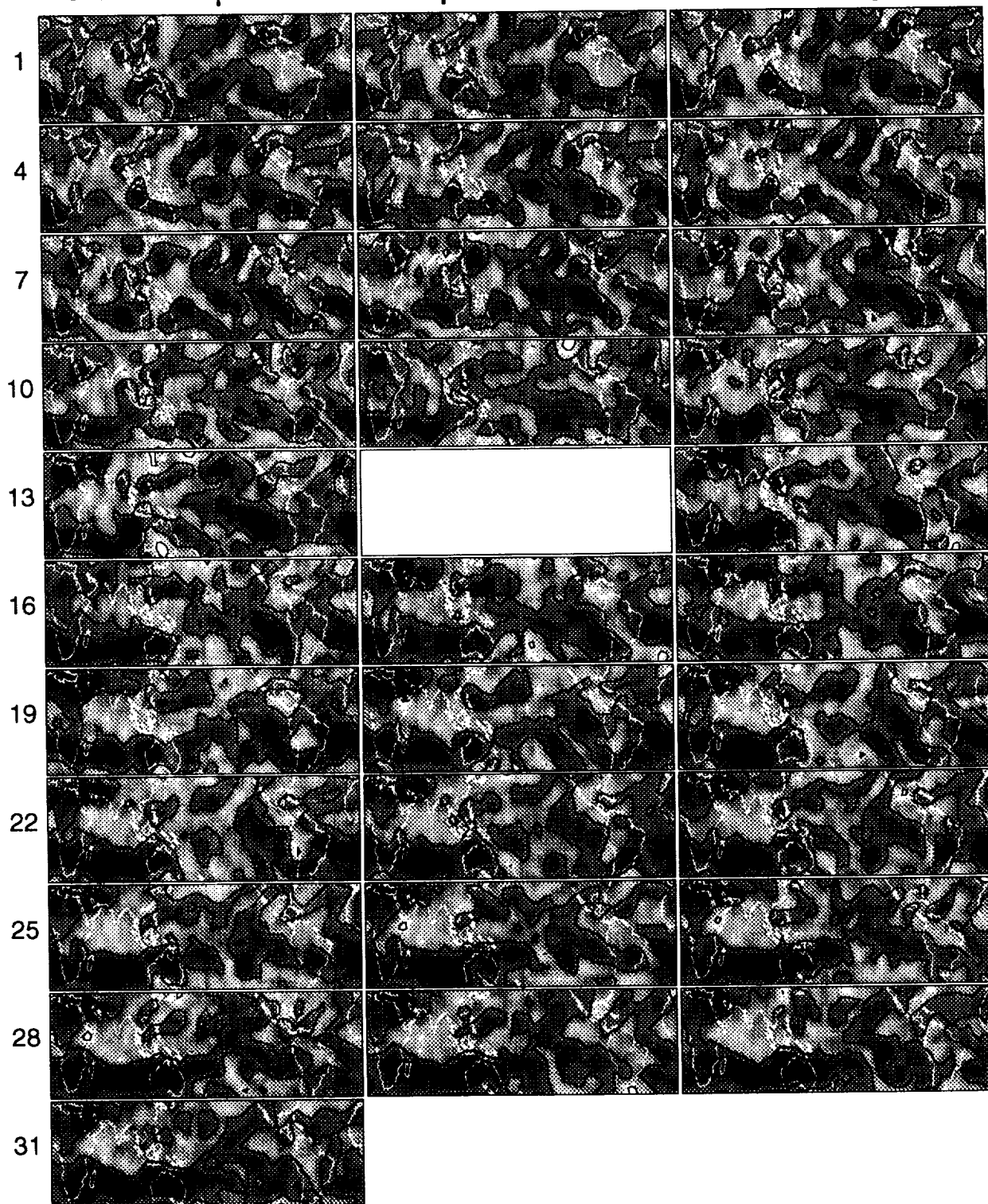
TOVS 6.5 μm Water Vapor Band

April 1990



TOVS 6.5 μm Water Vapor Band

May 1990



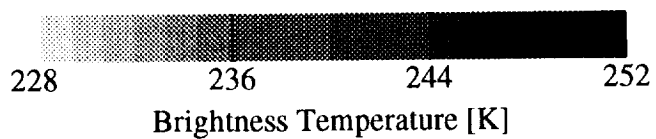
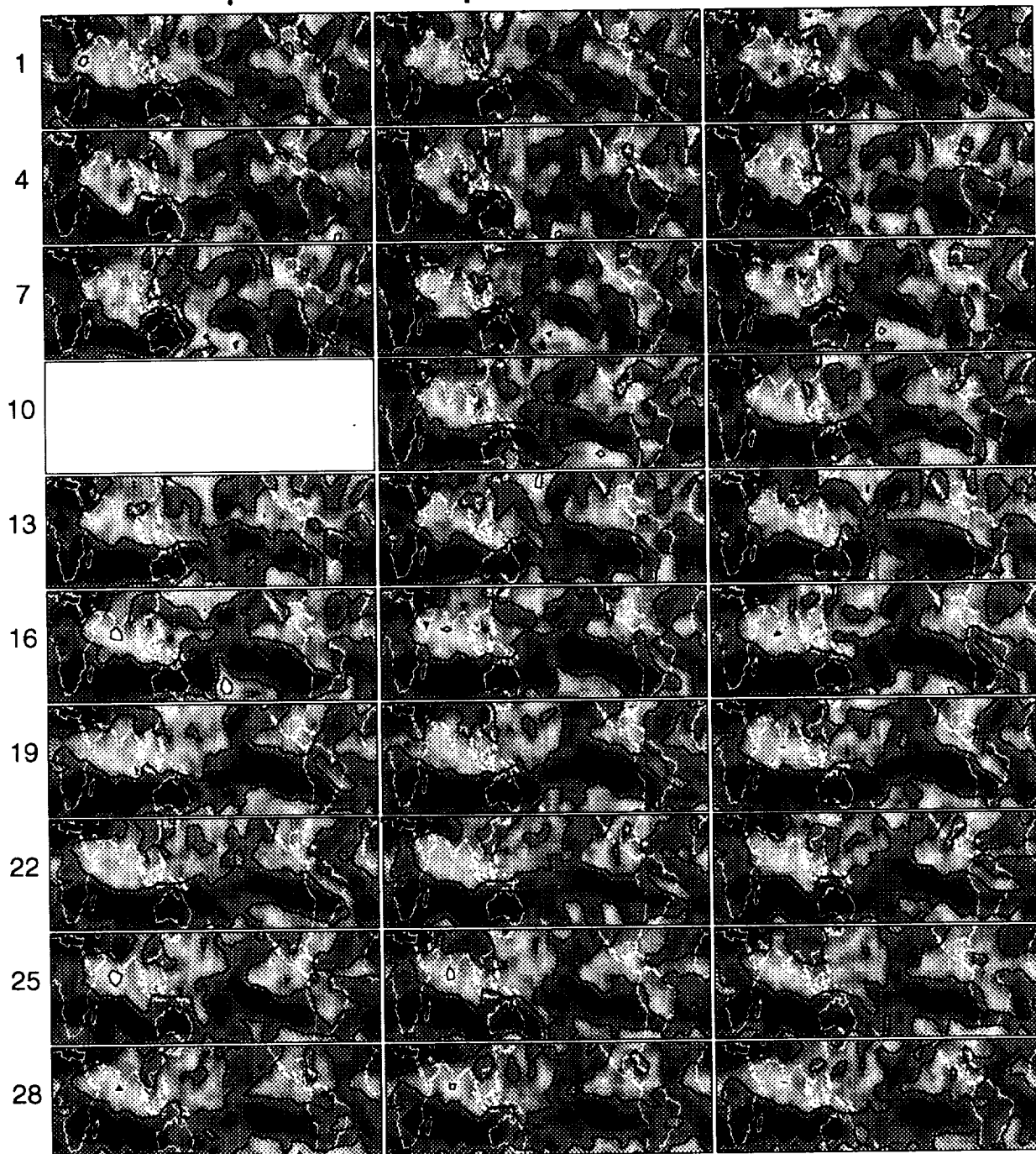
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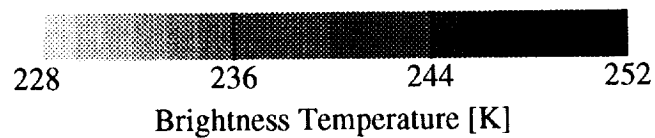
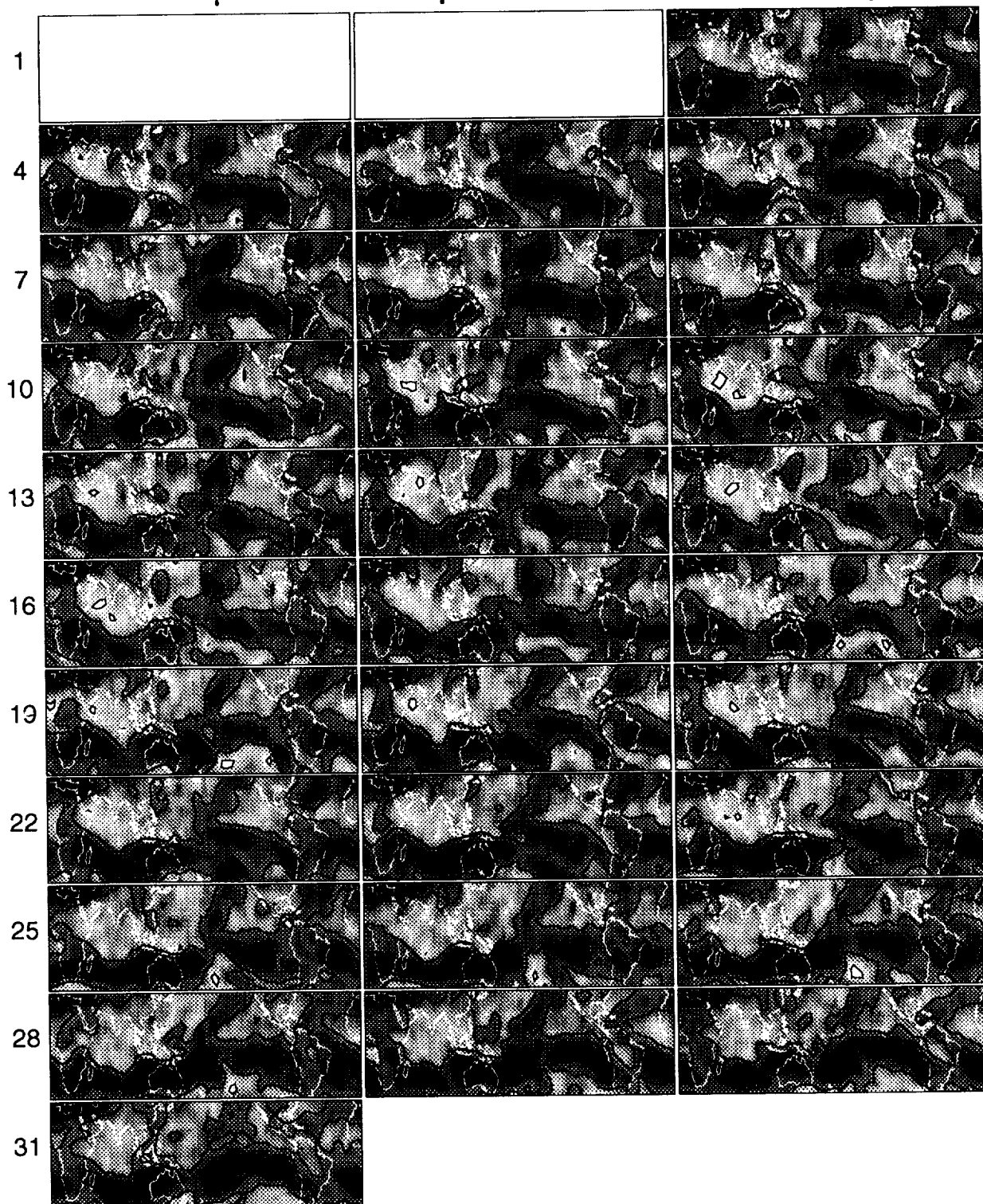
TOVS 6.5 μm Water Vapor Band

June 1990



TOVS 6.5 μm Water Vapor Band

July 1990



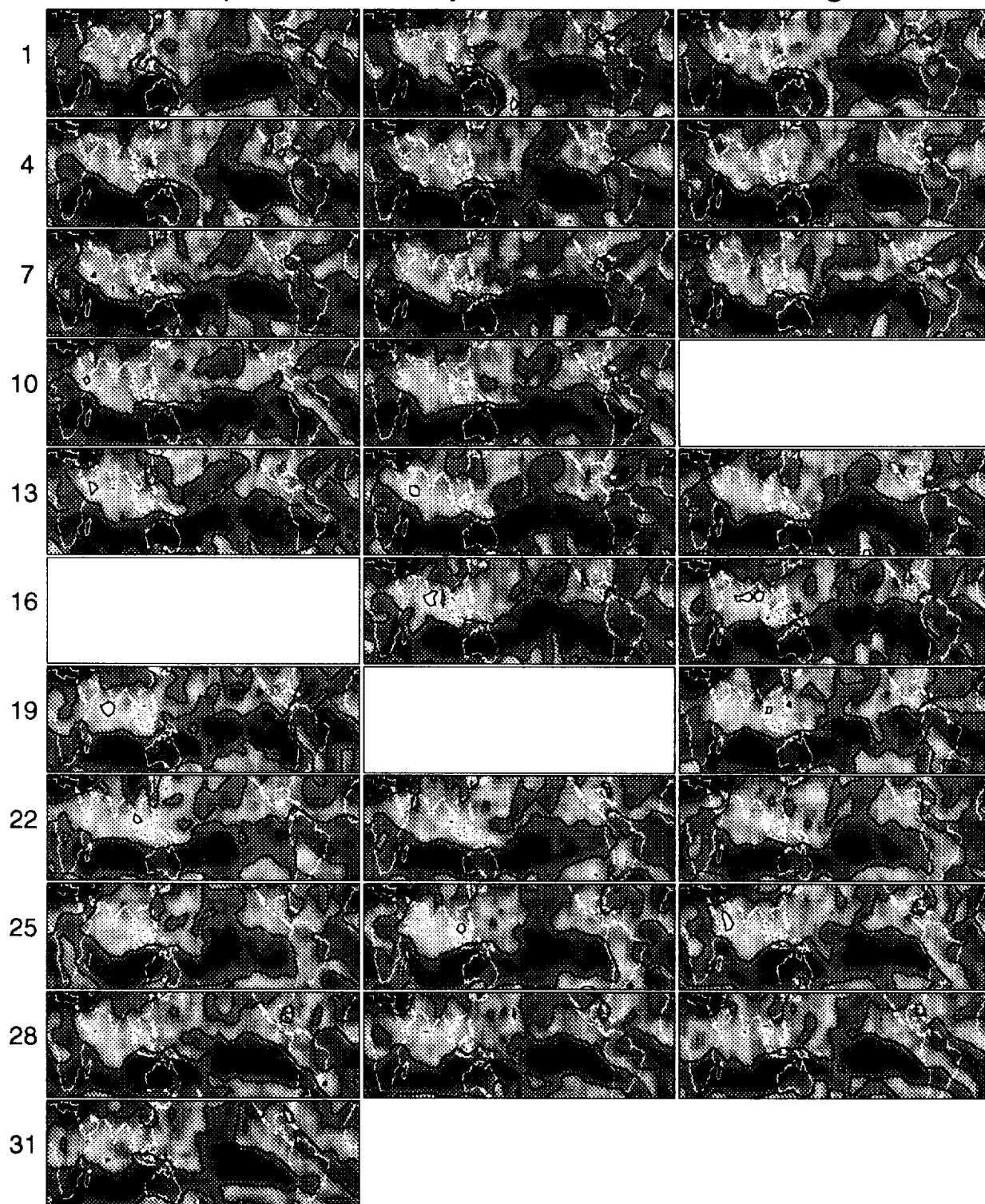
A-279

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TOVS 6.5 μm Water Vapor Band

August 1990



228

236

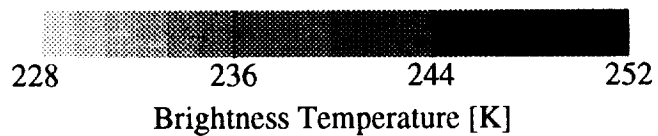
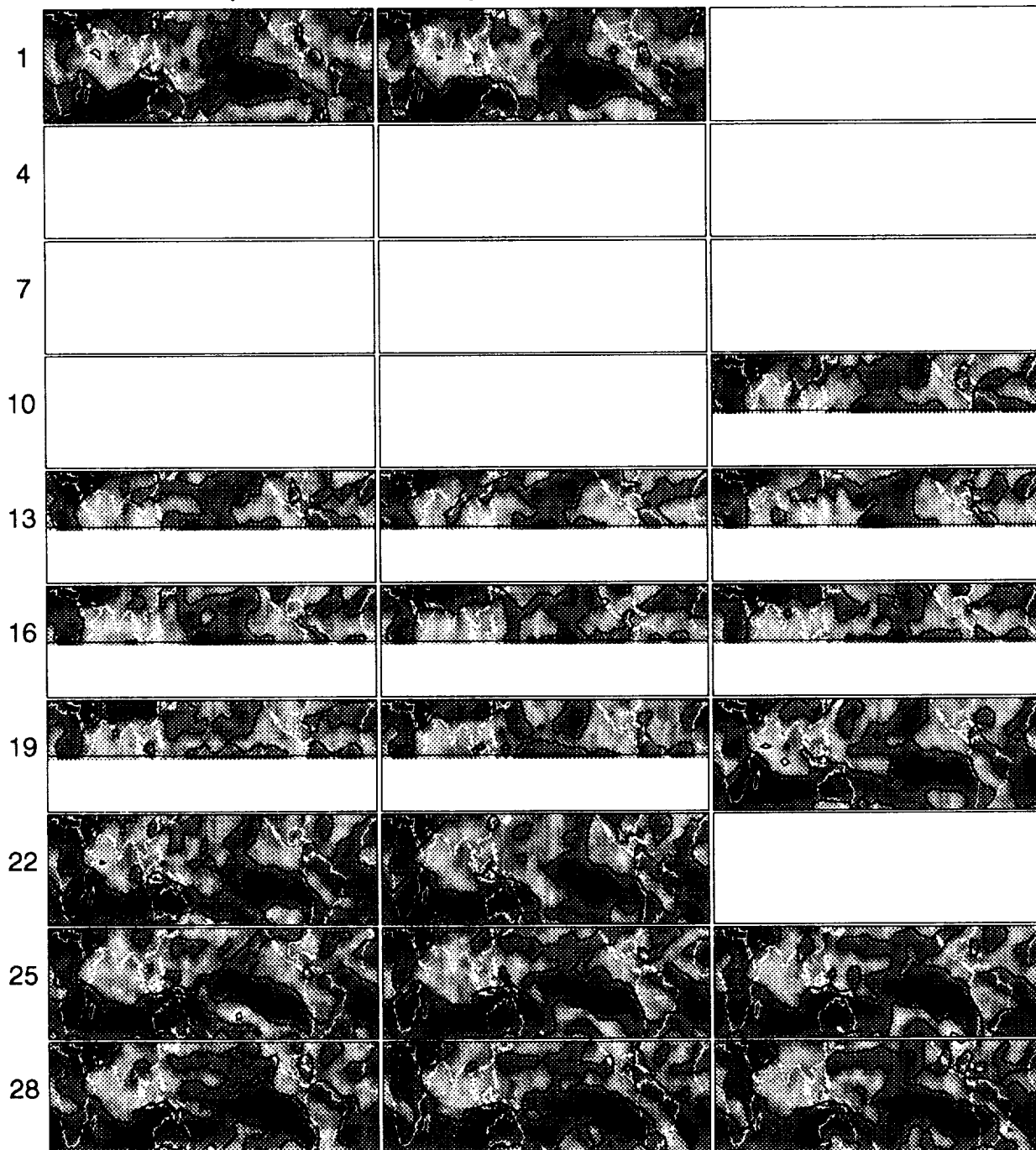
244

252

Brightness Temperature [K]

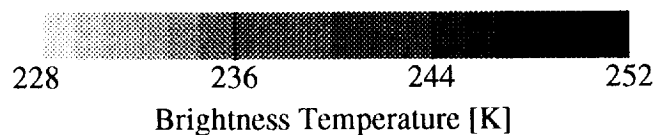
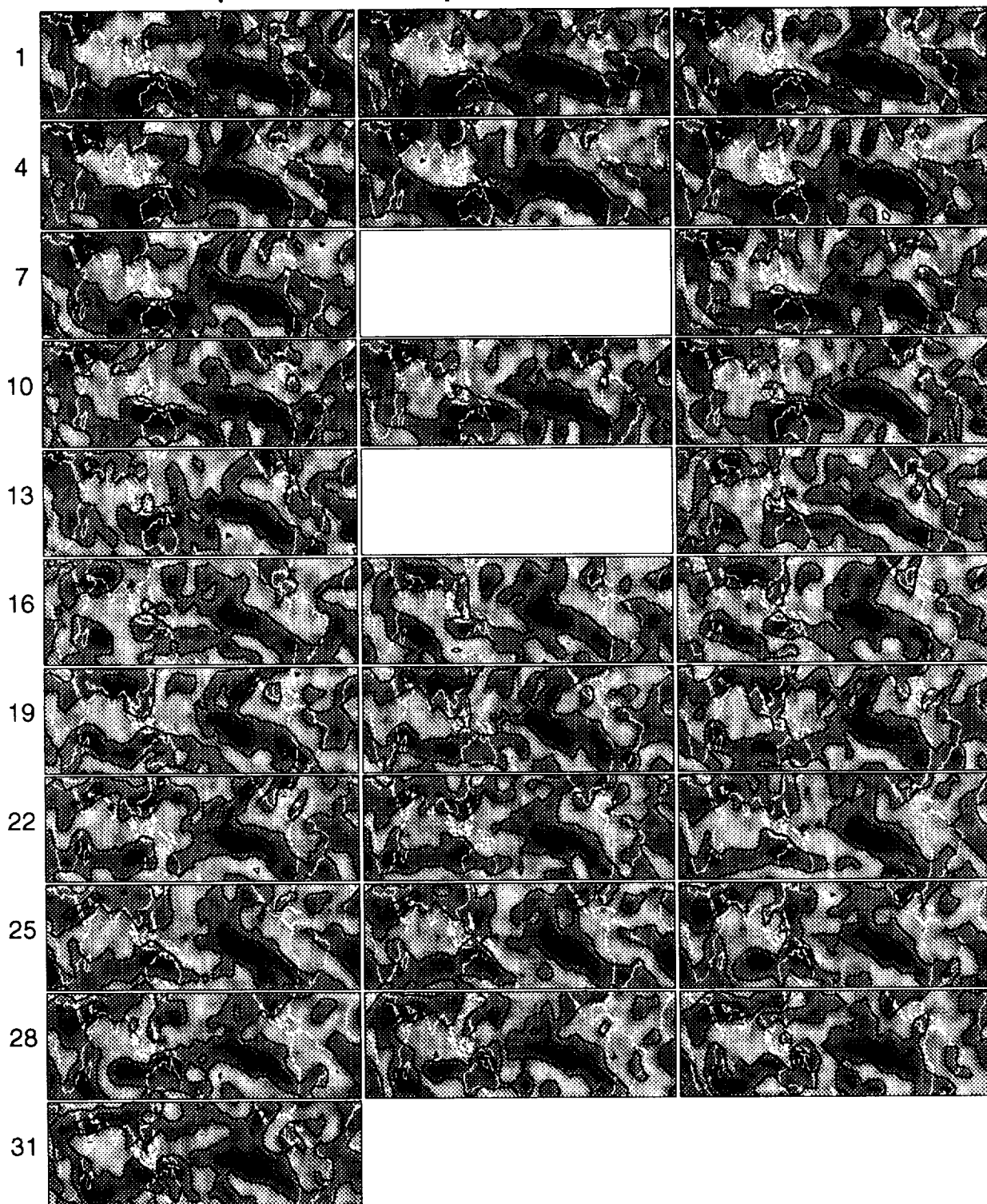
TOVS 6.5 μm Water Vapor Band

September 1990



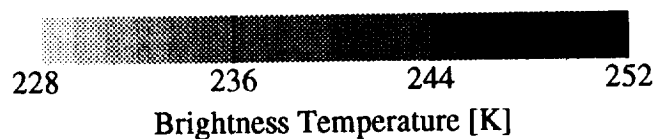
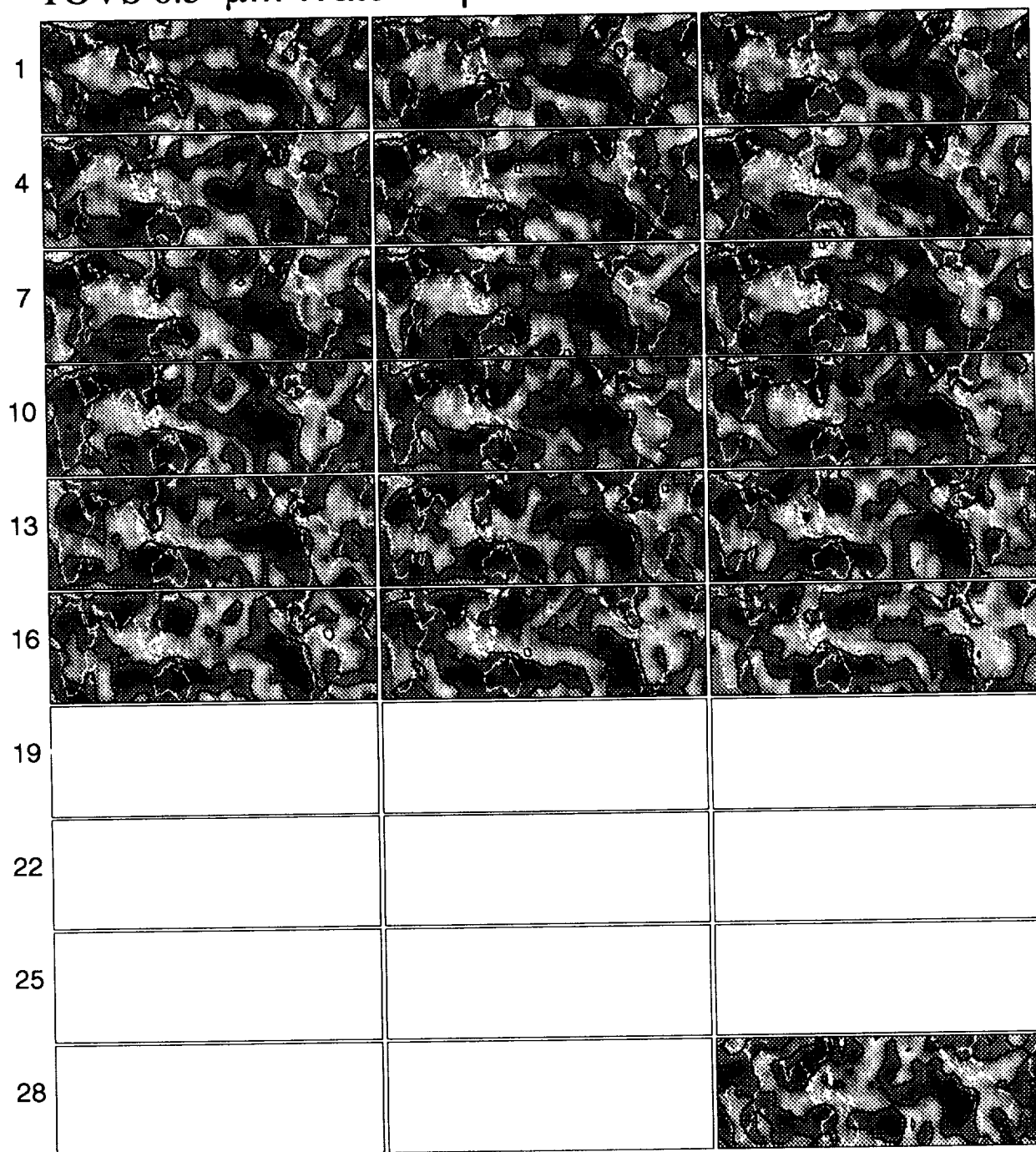
TOVS 6.5 μm Water Vapor Band

October 1990



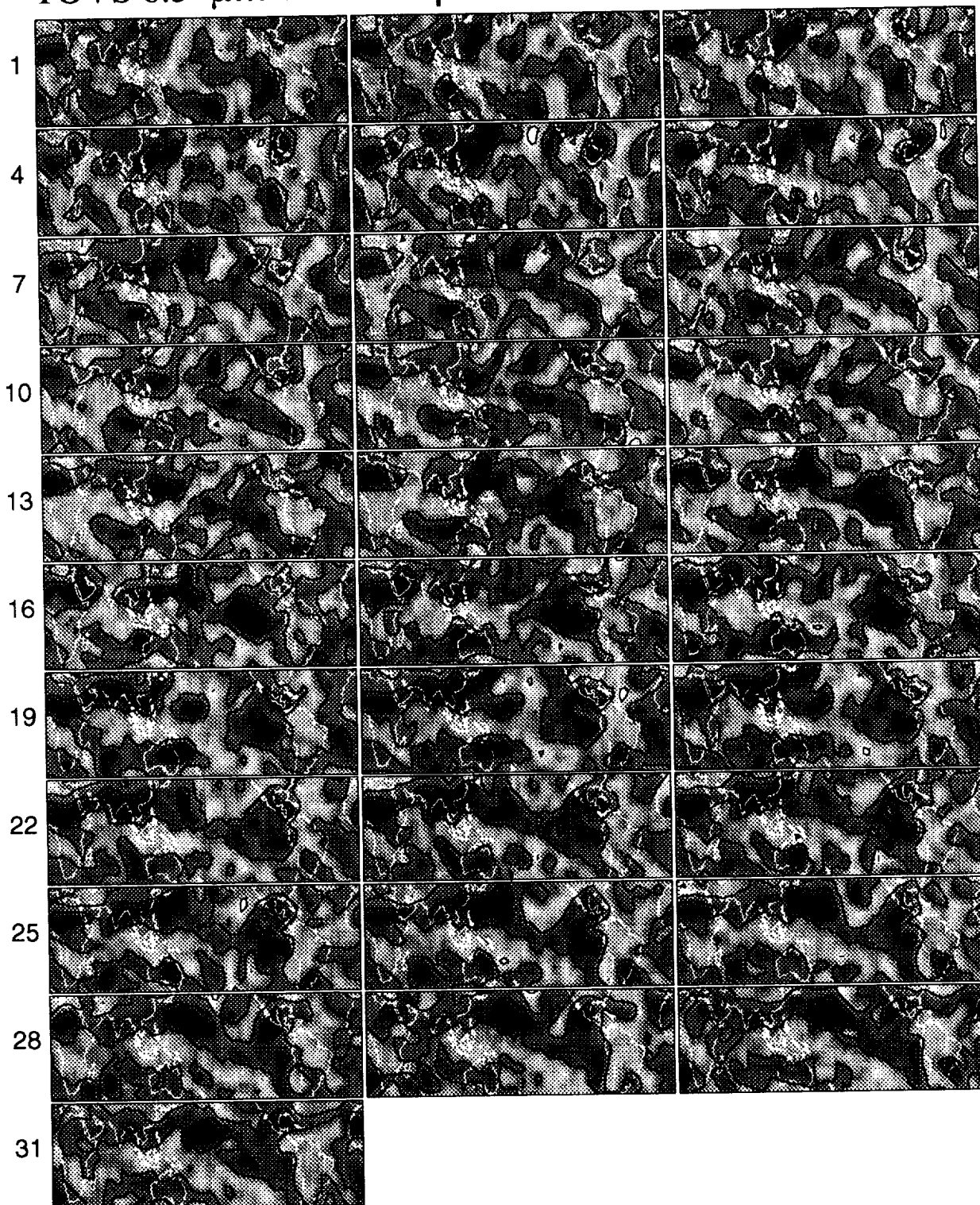
TOVS 6.5 μm Water Vapor Band

November 1990



TOVS 6.5 μm Water Vapor Band

December 1990



228

236

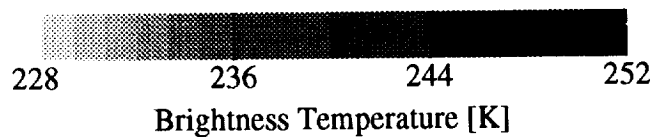
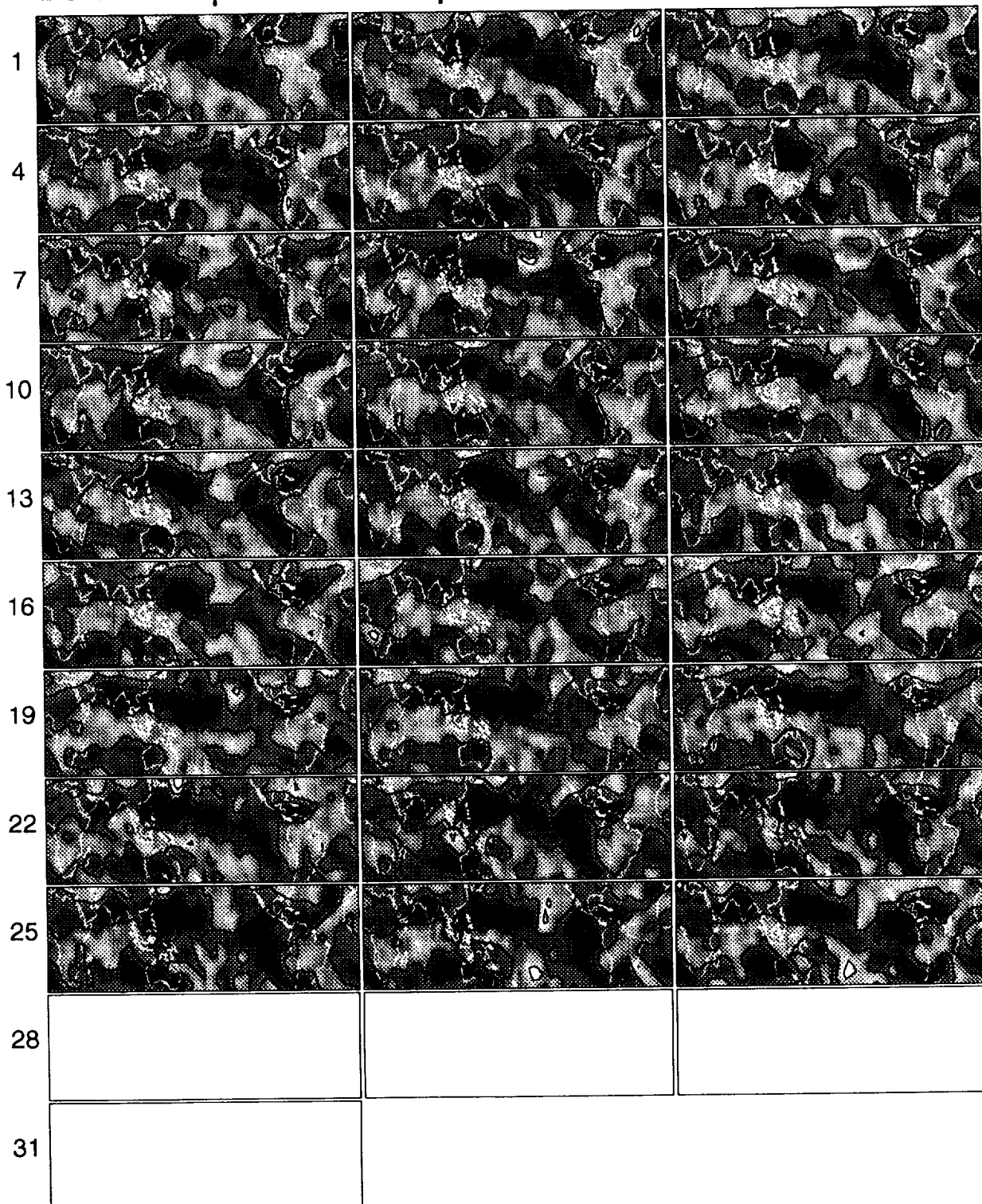
244

252

Brightness Temperature [K]

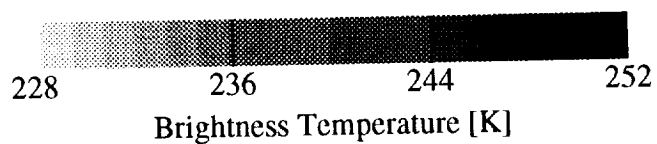
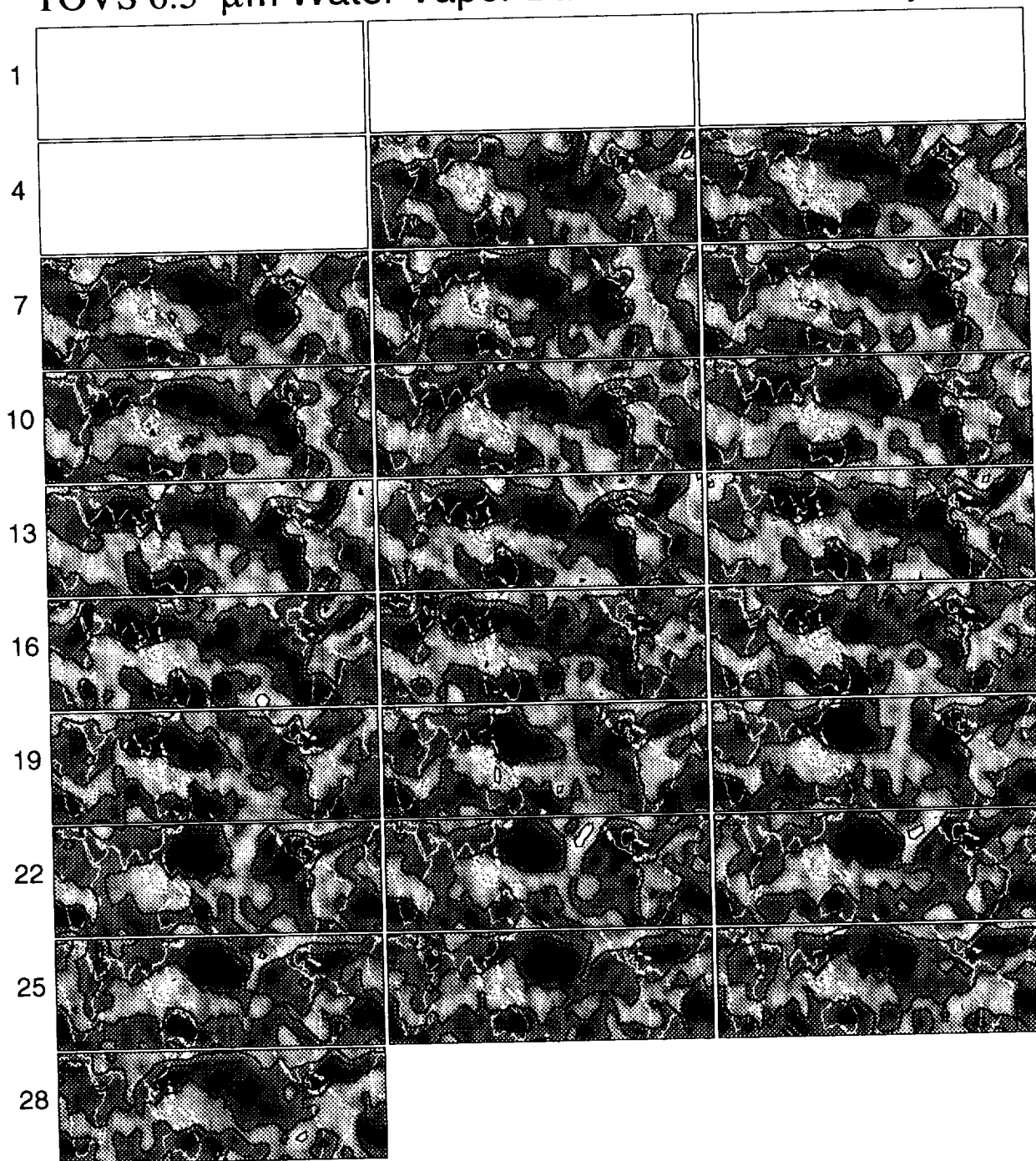
TOVS 6.5 μm Water Vapor Band

January 1991



TOVS 6.5 μm Water Vapor Band

February 1991



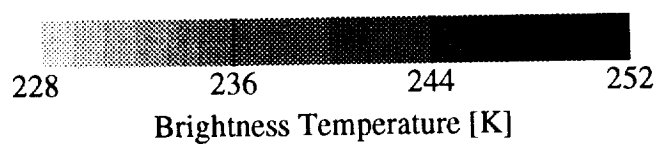
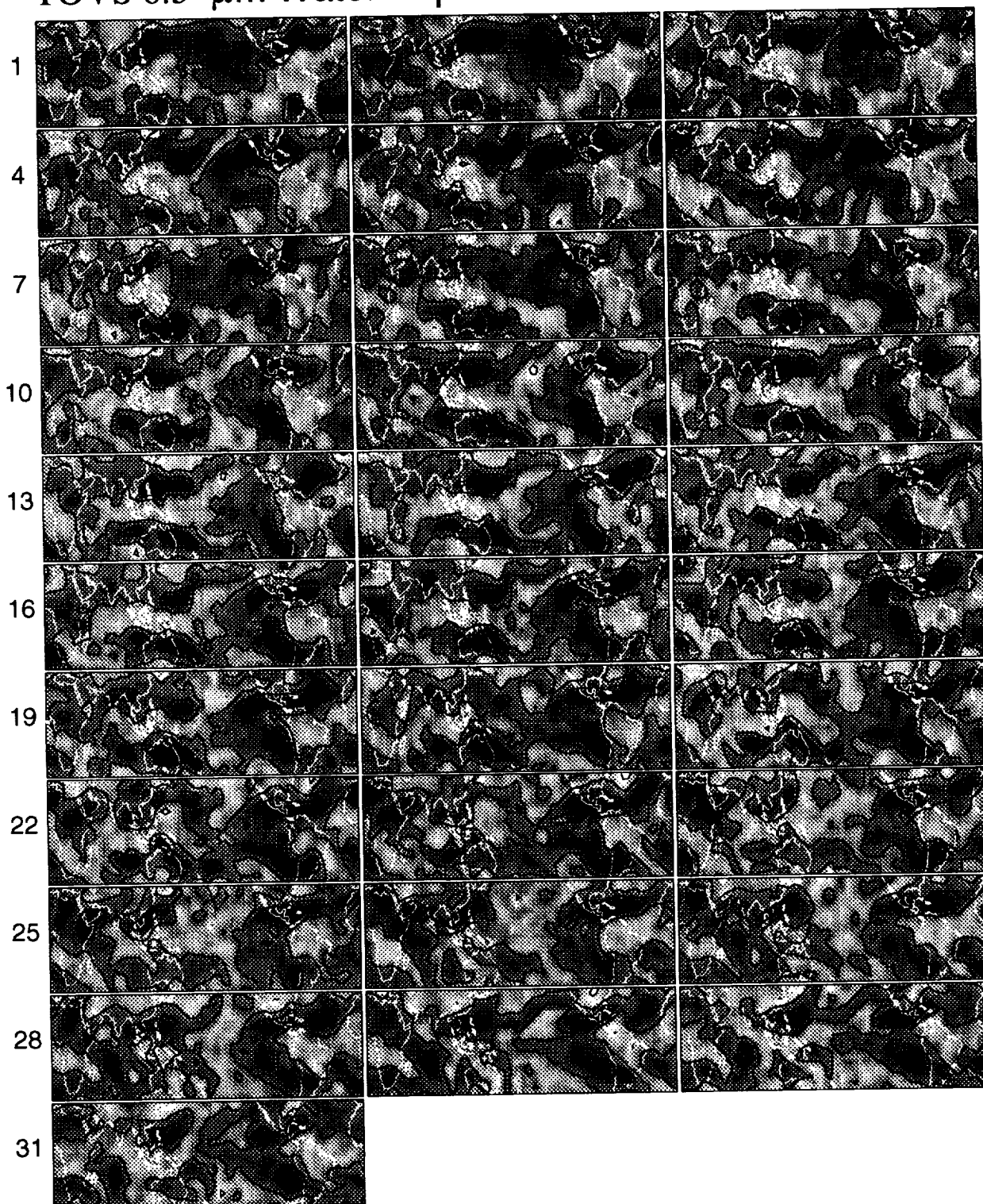
A-293

A-292 PREVIOUSLY FILMED

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TOVS 6.5 μm Water Vapor Band

March 1991



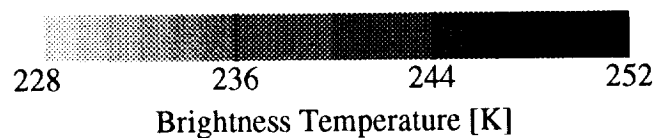
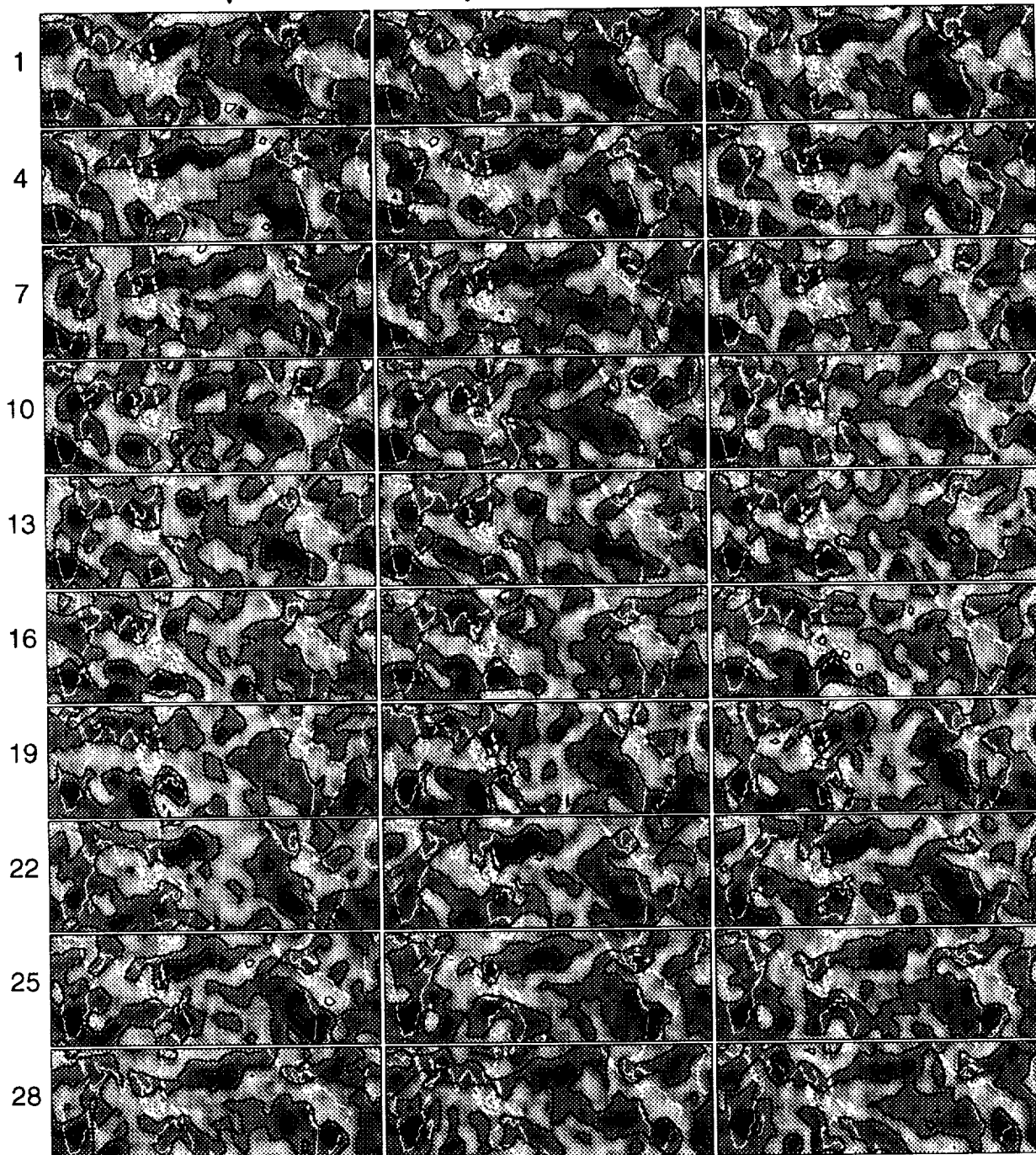
A-295

A-294

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TOVS 6.5 μm Water Vapor Band

April 1991



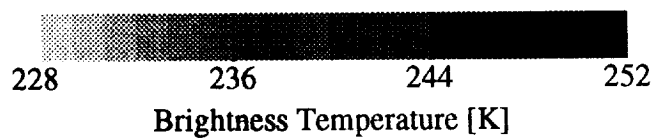
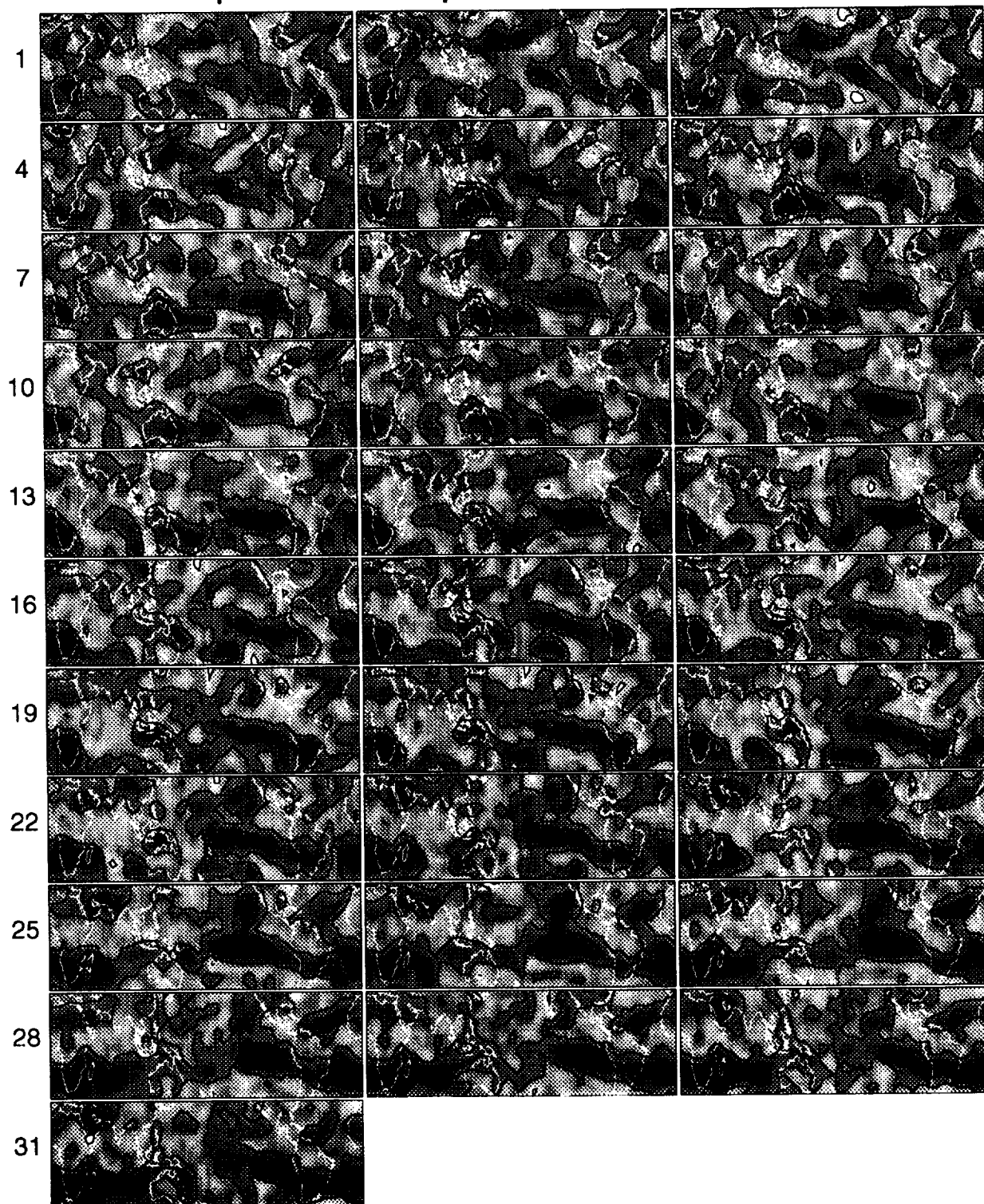
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A-297

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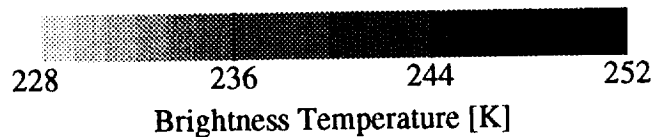
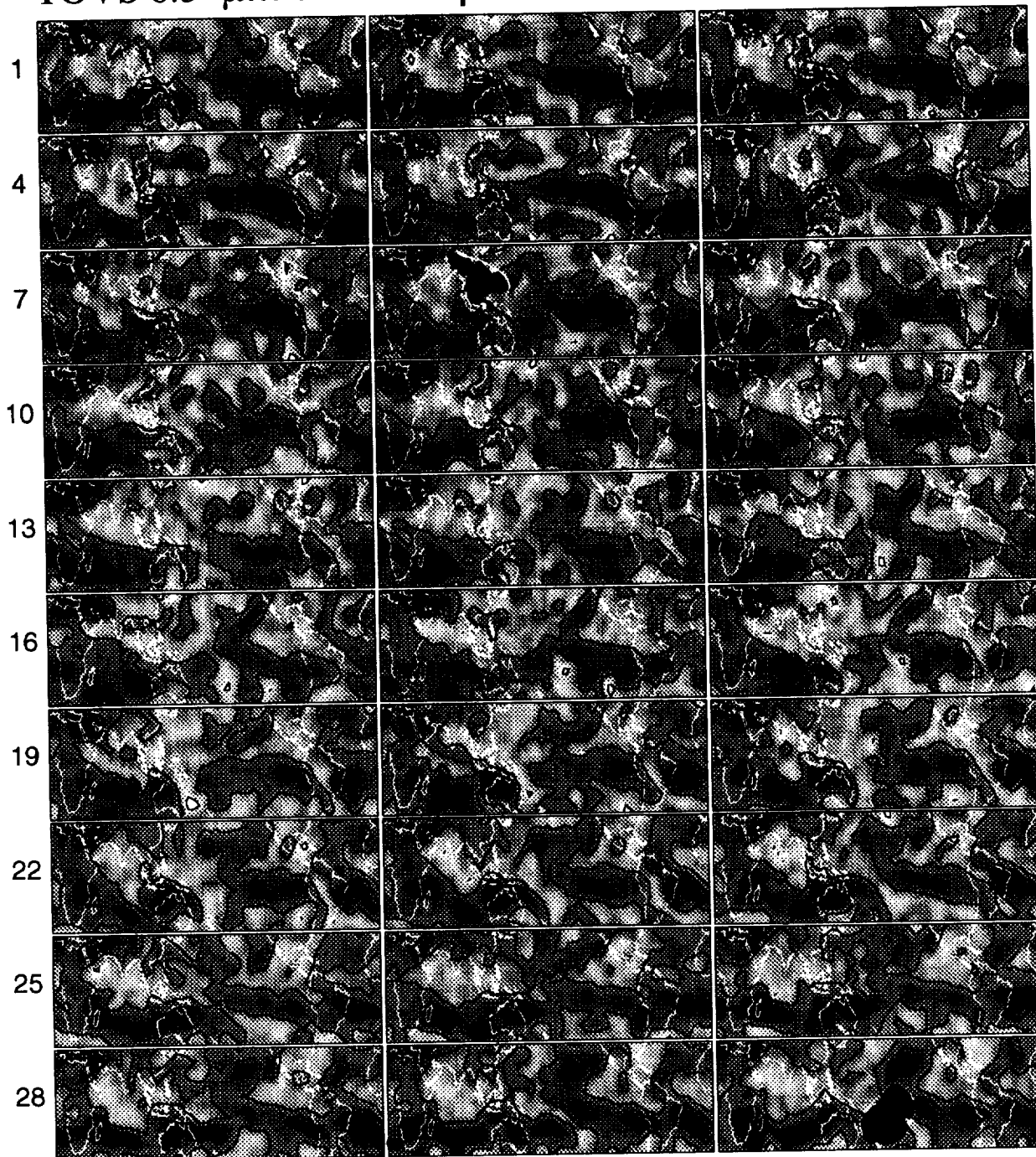
TOVS 6.5 μm Water Vapor Band

May 1991

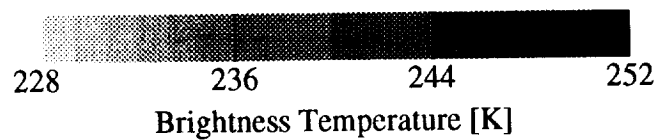


TOVS 6.5 μ m Water Vapor Band

June 1991



July 1991

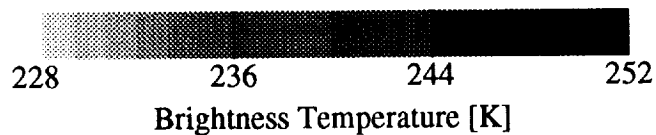
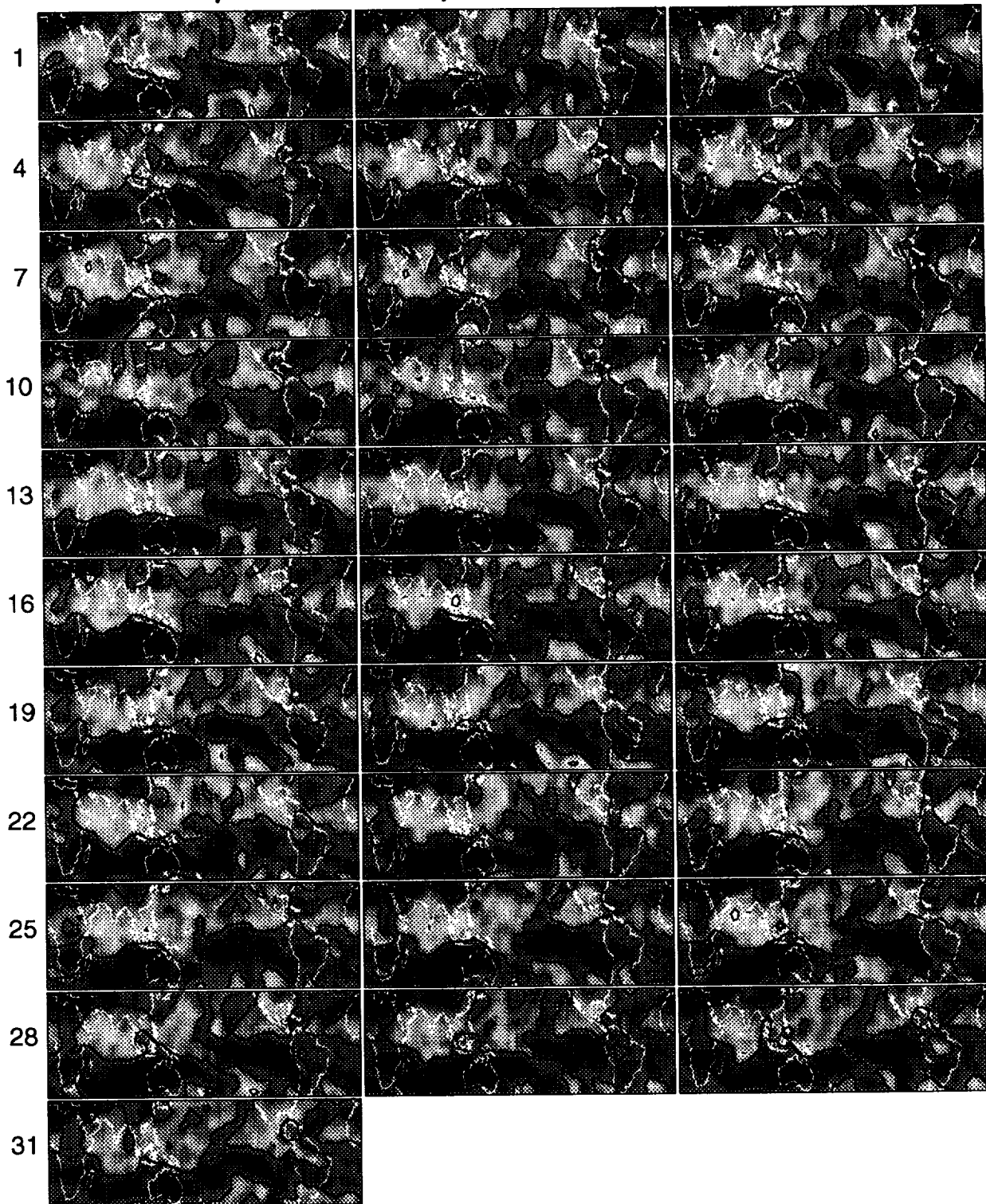


A-302 **A-303**

1970-1971

TOVS 6.5 μm Water Vapor Band

August 1991

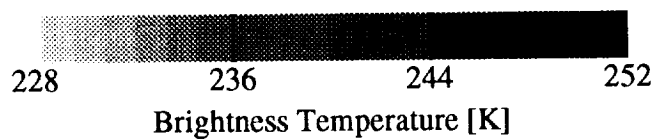
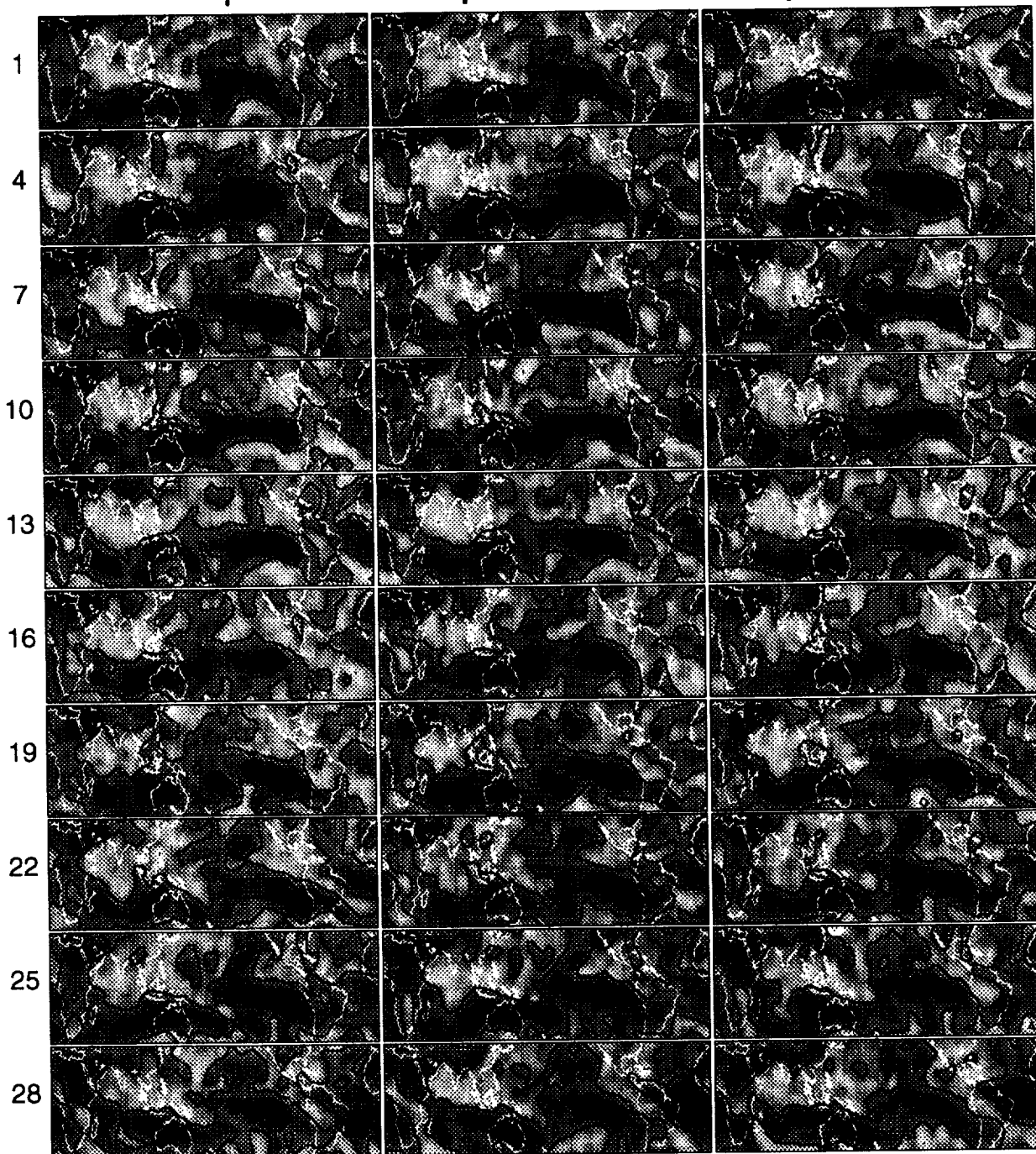


A-304 A-305

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TOVS 6.5 μm Water Vapor Band

September 1991



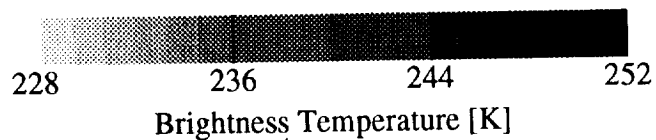
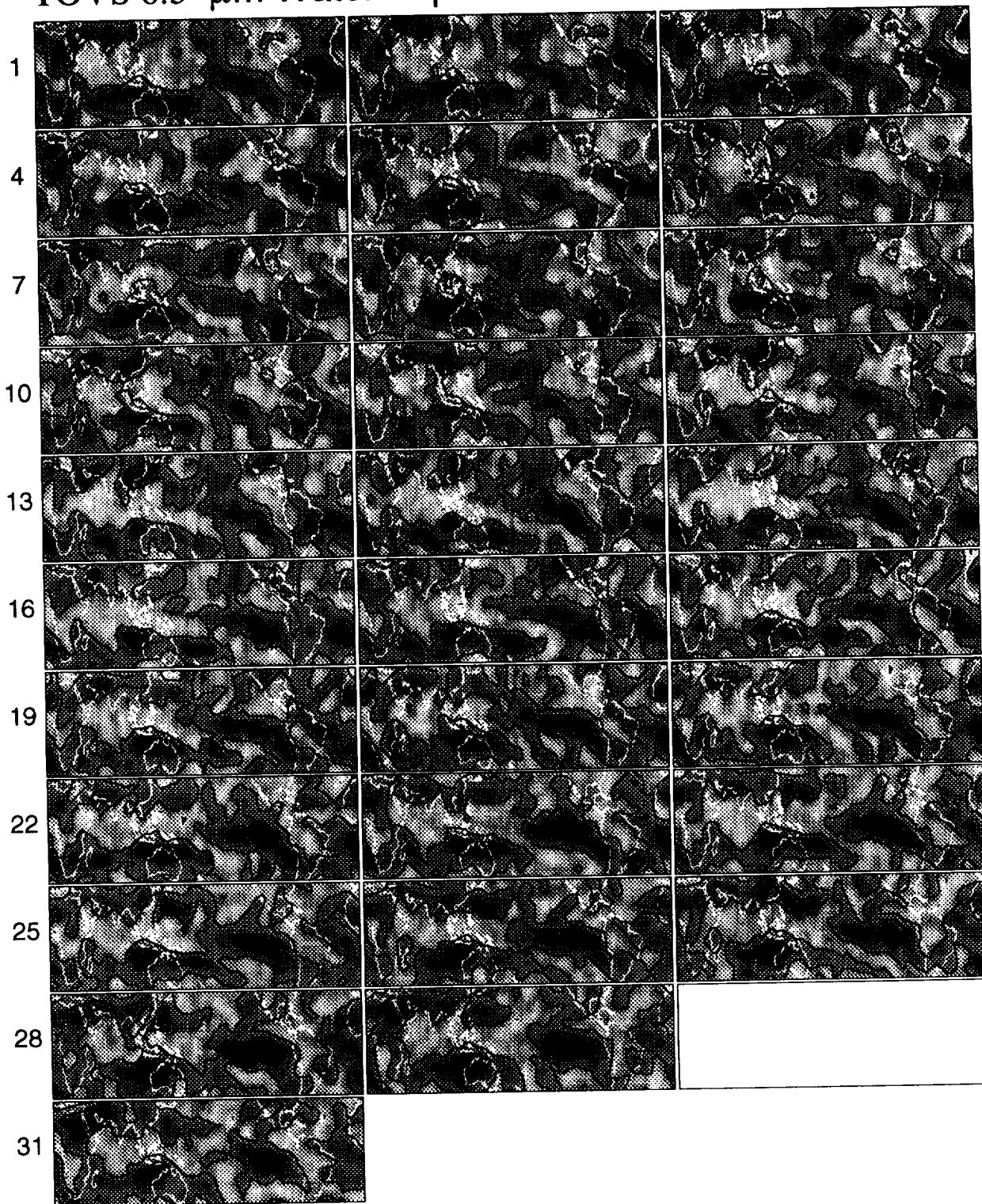
A-307

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TOVS 6.5 μm Water Vapor Band

October 1991



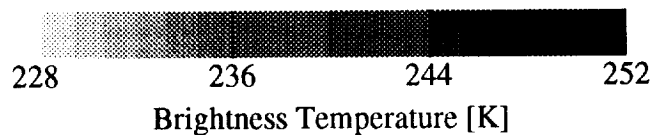
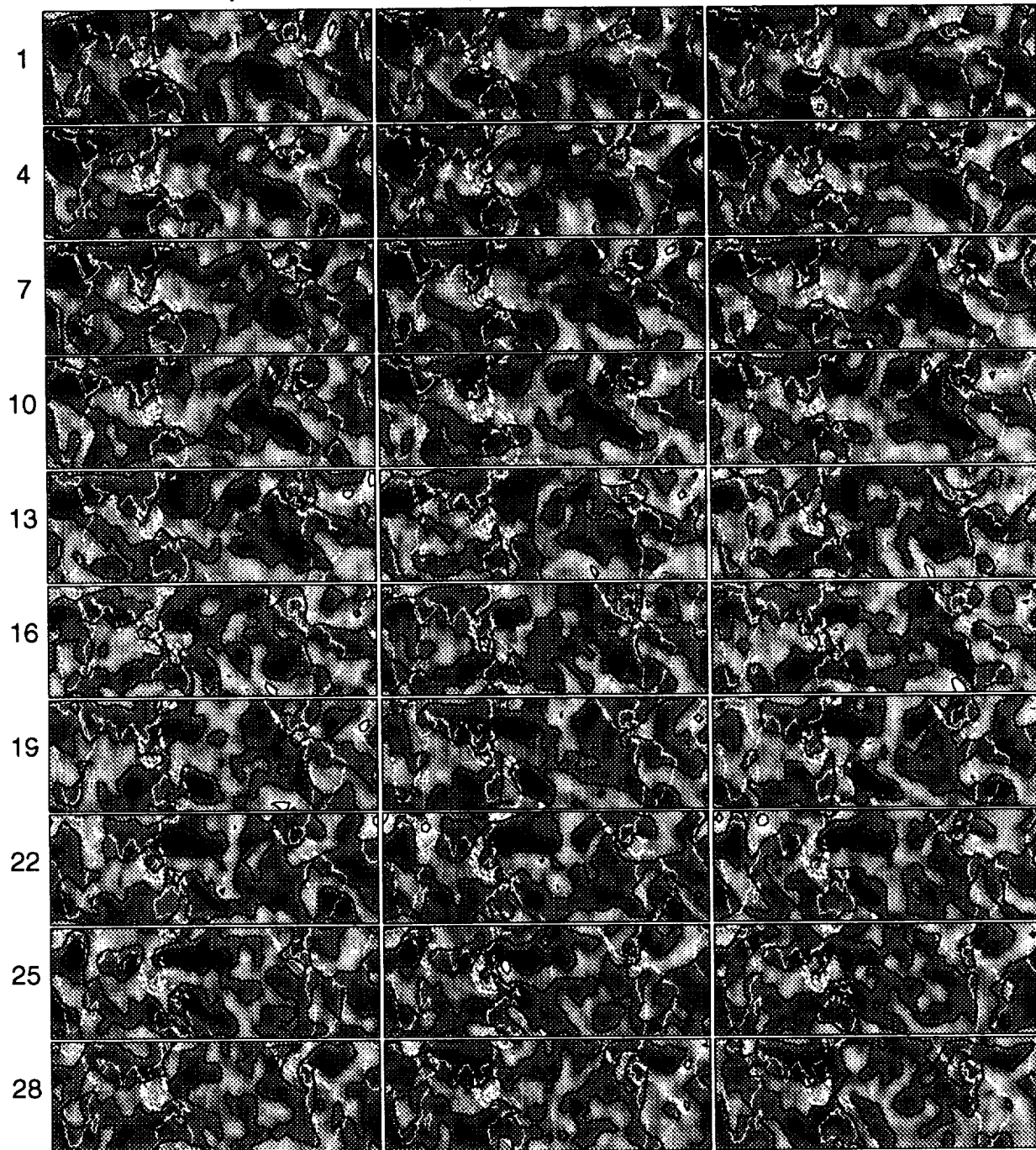
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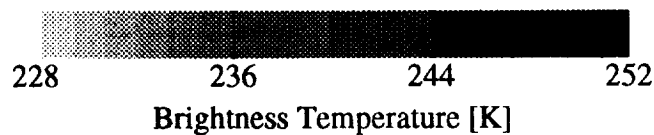
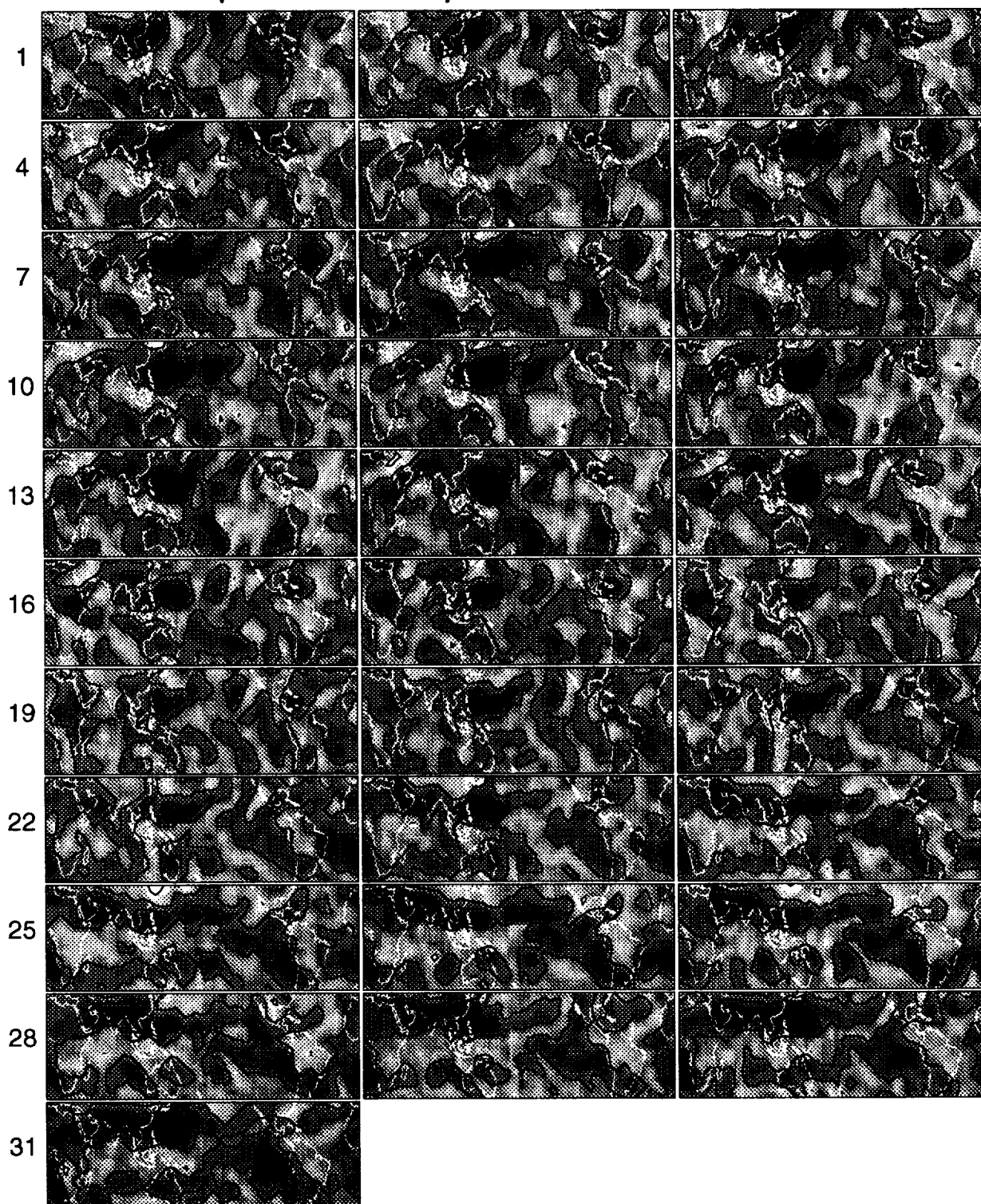
TOVS 6.5 μm Water Vapor Band

November 1991



TOVS 6.5 μm Water Vapor Band

December 1991

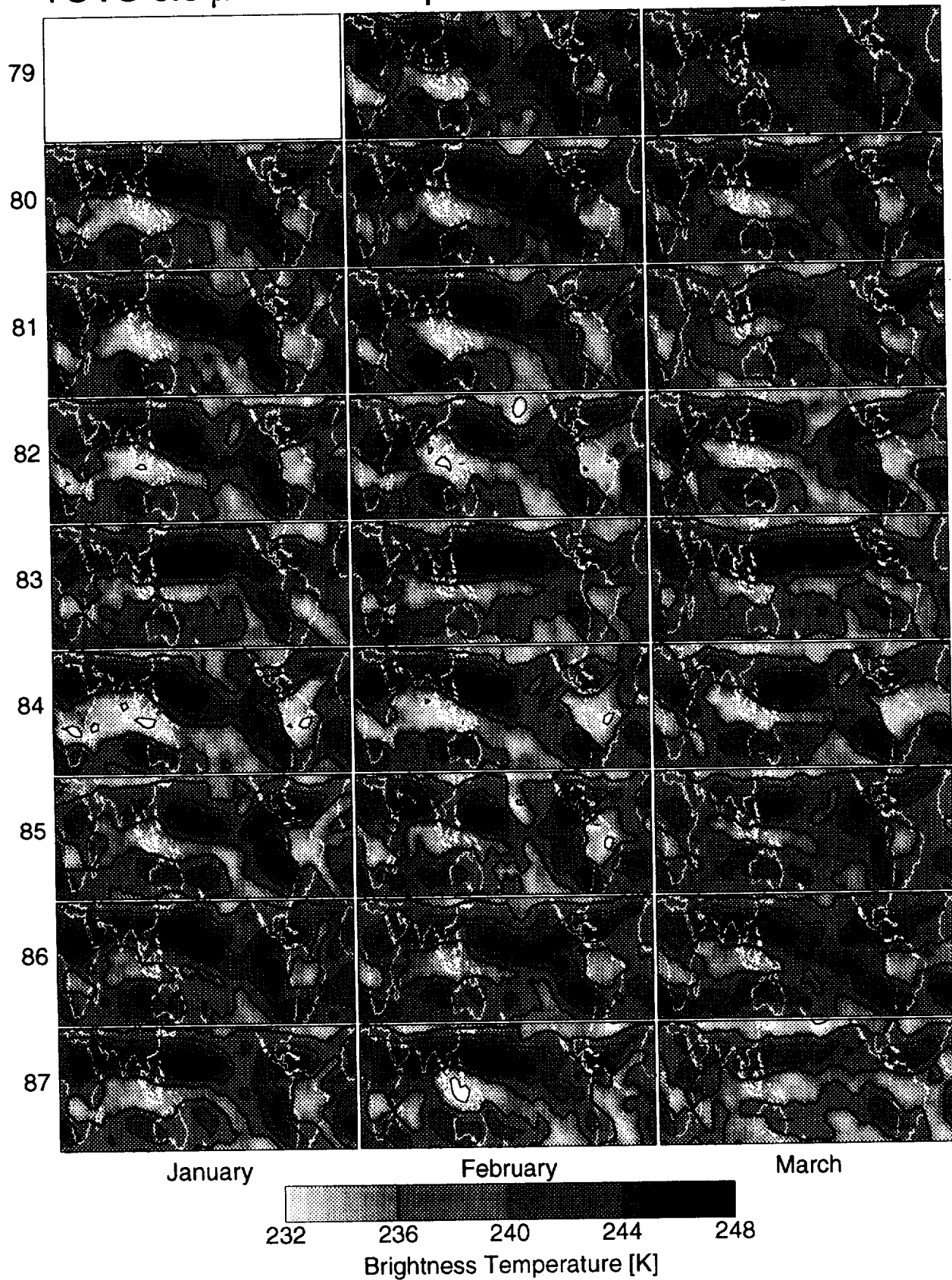


APPENDIX B (MONTHLY IMAGES)

TOVS "6.5" μm IMAGES MEAN FOR EACH MONTH IN EVERY YEAR 1979-1991

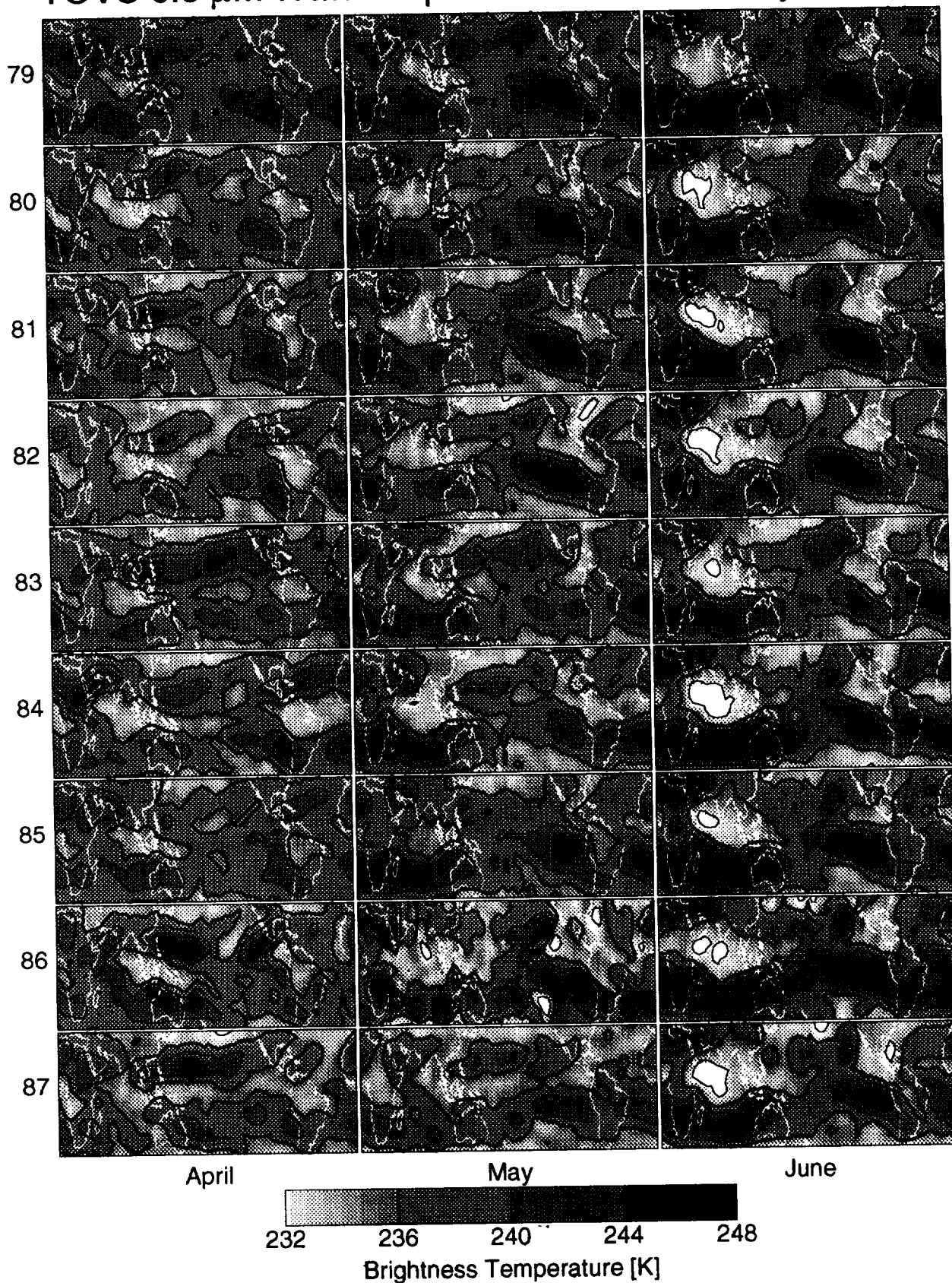
TOVS 6.5 μm Water Vapor Band

Monthly Average



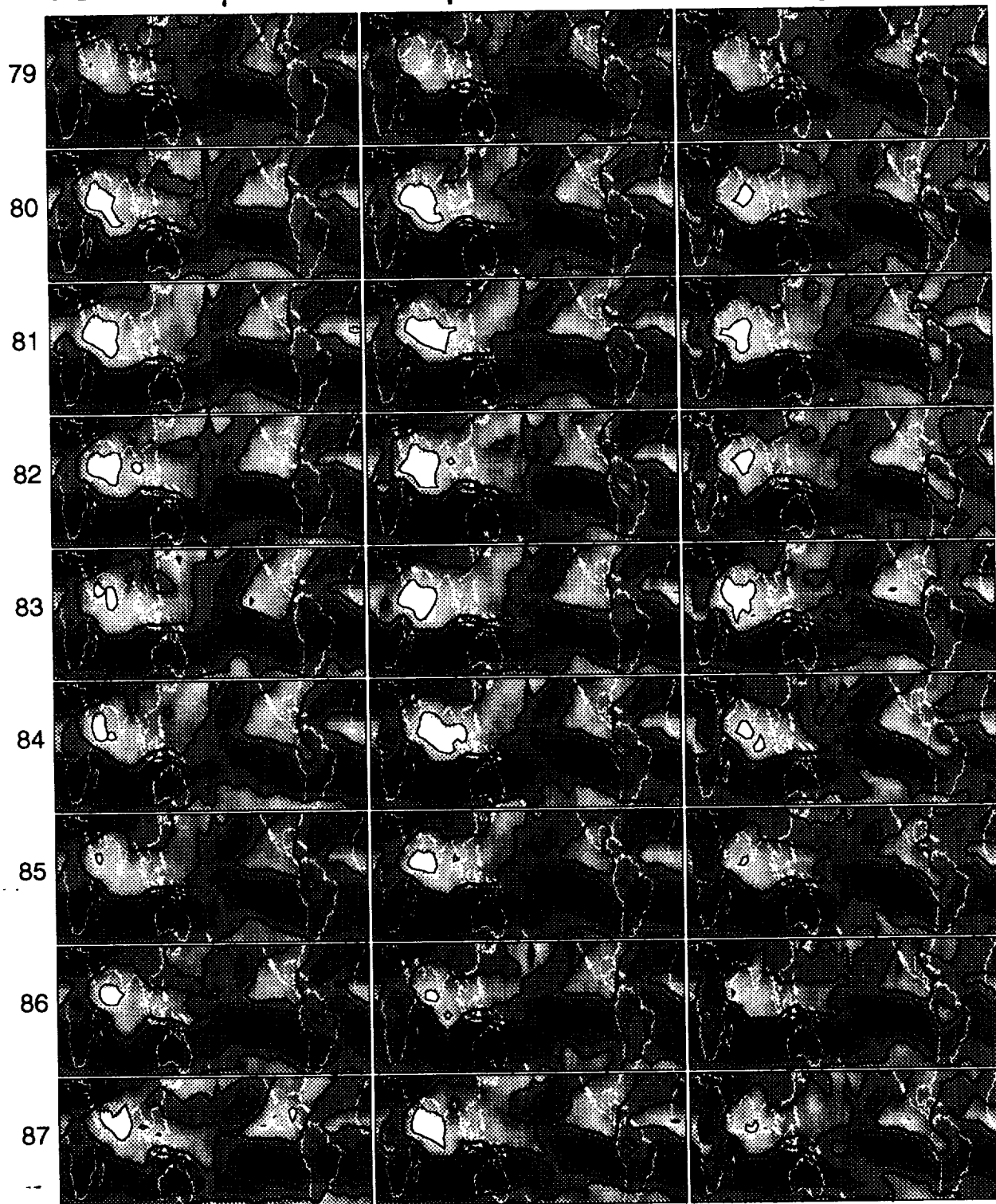
TOVS 6.5 μm Water Vapor Band

Monthly Average



TOVS 6.5 μm Water Vapor Band

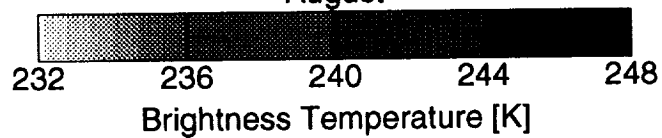
Monthly Average



July

August

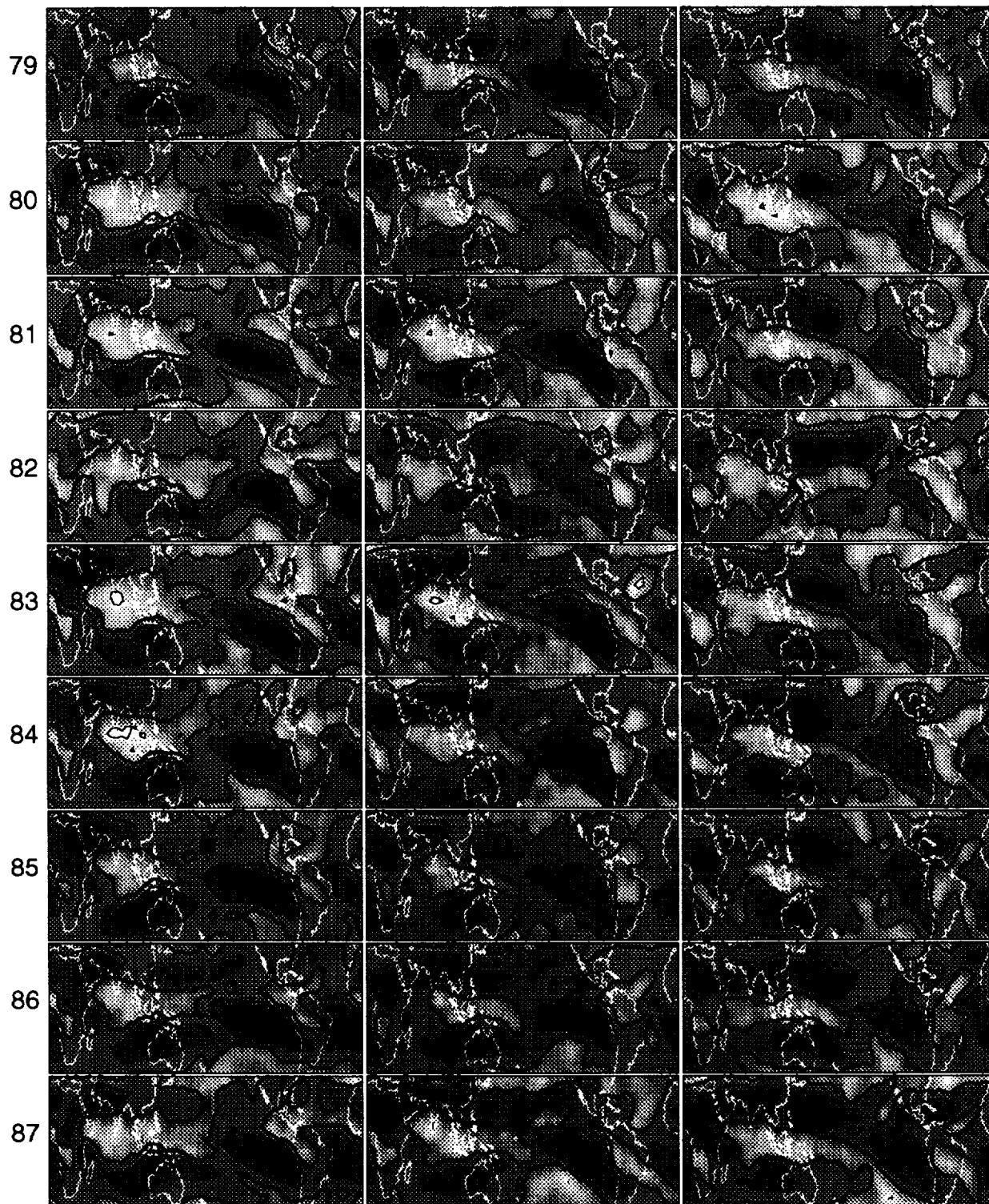
September



Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

Monthly Average



October

November

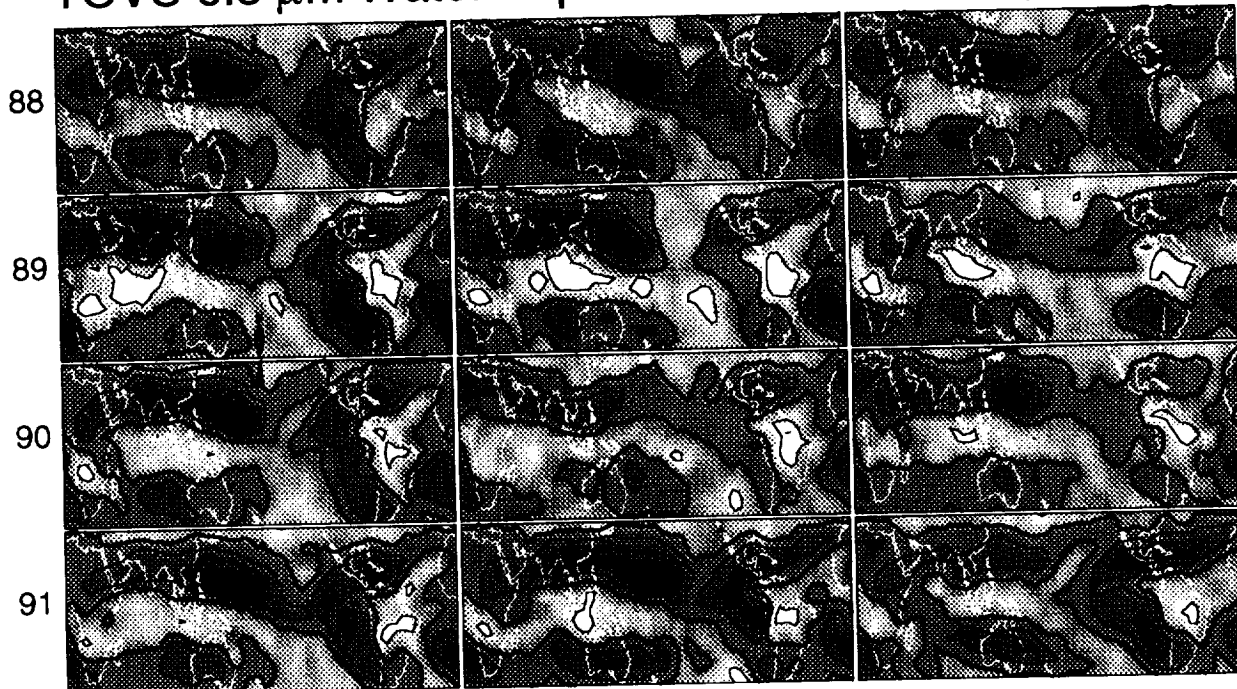
December



Brightness Temperature [K]

TOVS 6.5 μm Water Vapor Band

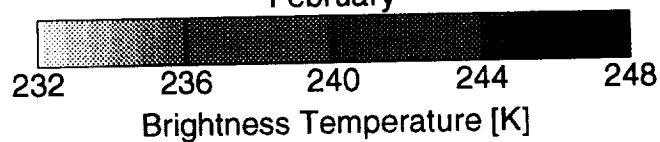
Monthly Average



January

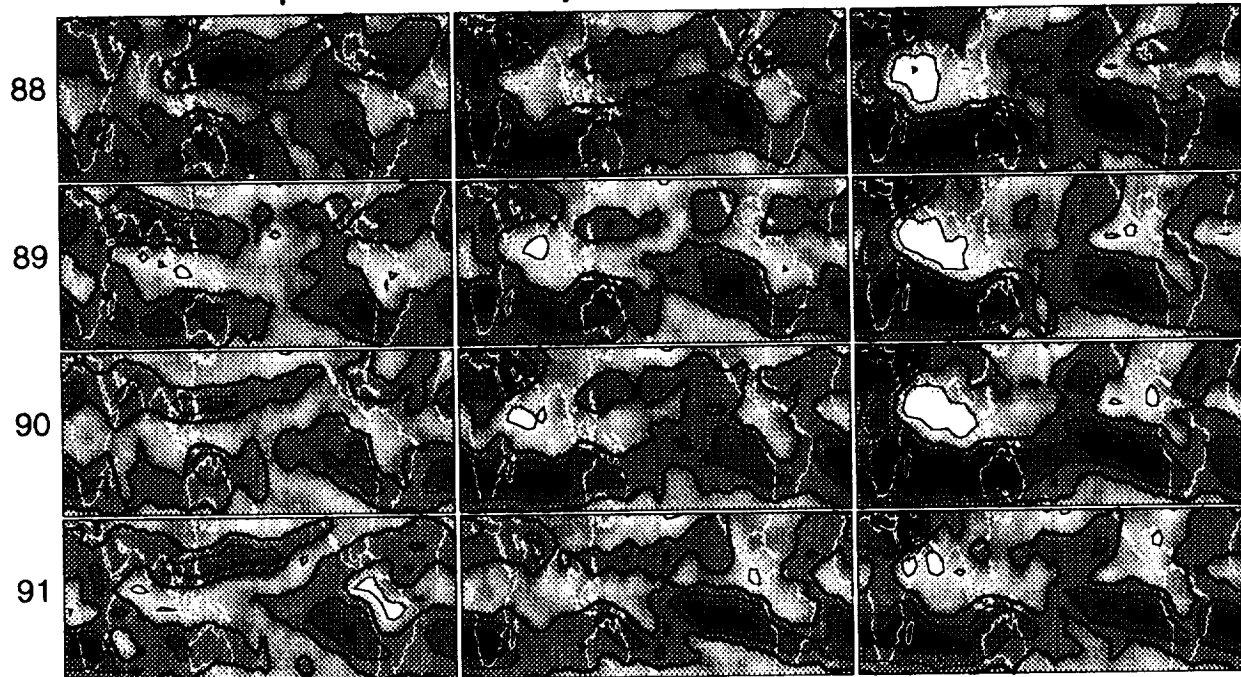
February

March



TOVS 6.5 μm Water Vapor Band

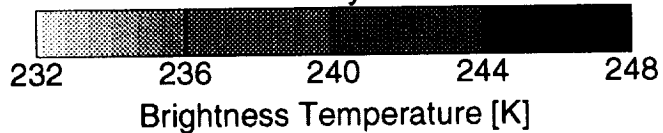
Monthly Average



April

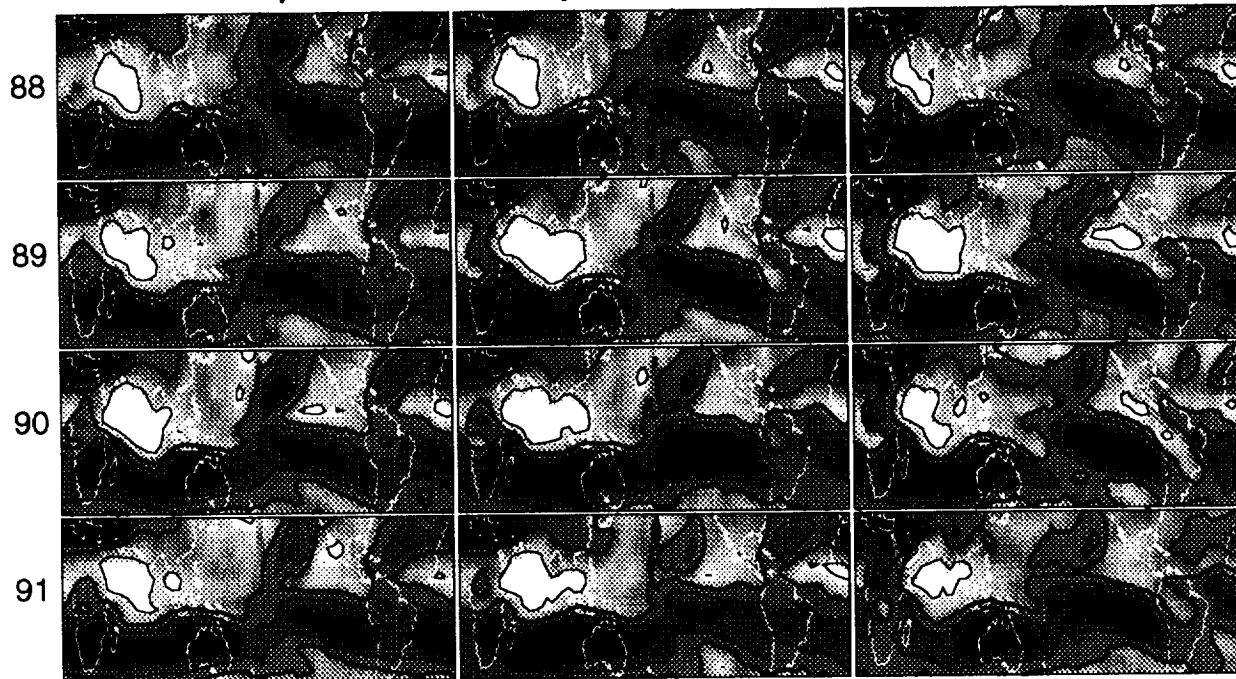
May

June



TOVS 6.5 μm Water Vapor Band

Monthly Average



July

August

September

232

236

240

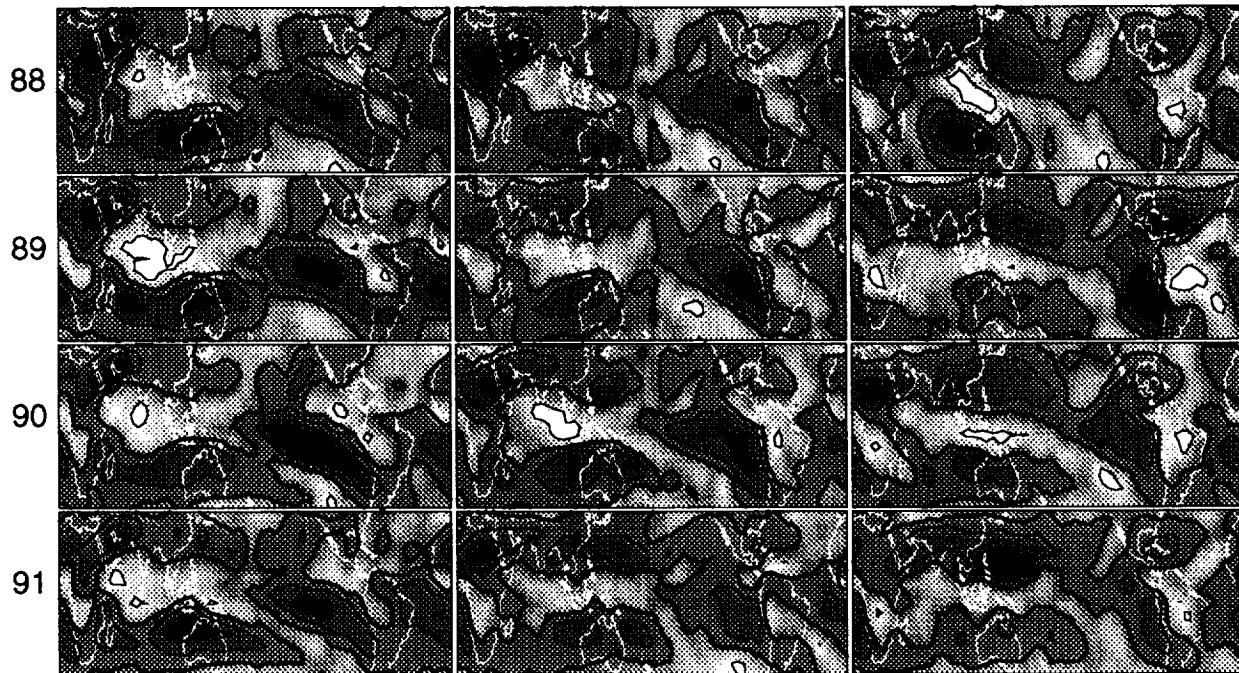
244

248

Brightness Temperature [K]

TOVS 6.5 μ m Water Vapor Band

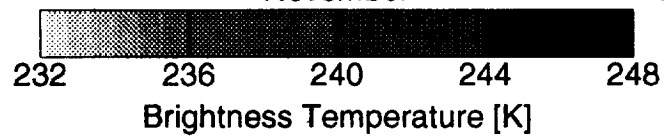
Monthly Average



October

November

December



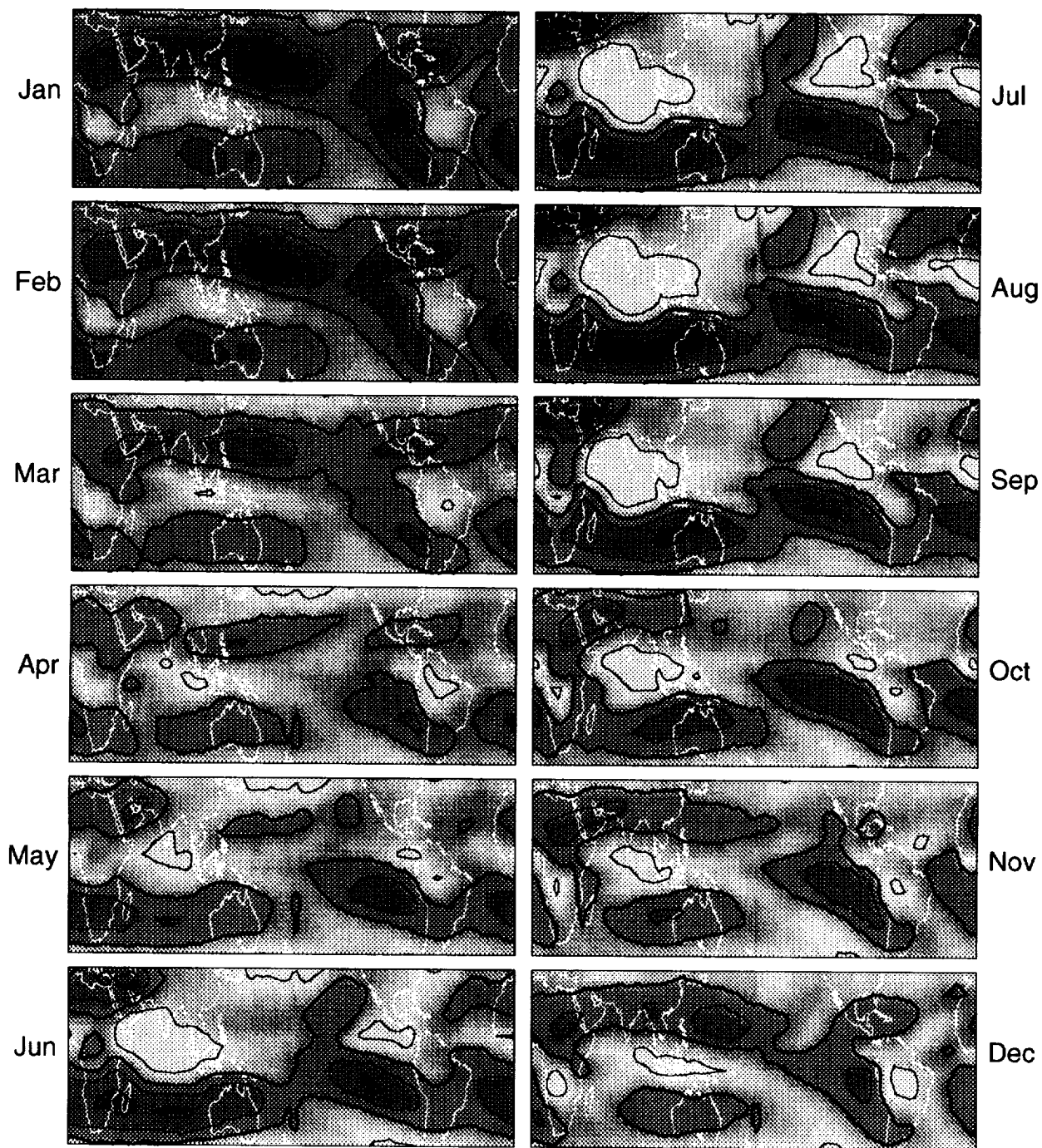
APPENDIX C (ANNUAL CYCLE)

TOVS "6.5" μm IMAGES

12 MONTHLY MEANS, AVERAGED OVER 13 YEARS

1979-1991

TOVS 6.5μm Water Vapor Band Monthly Average, 1979-1991



232 236 240 244 248
Brightness Temperature [K]
